DAILY TIME STEP SIMULATION WITH A PRIORITY ORDER BASED SURFACE WATER ALLOCATION MODEL

A Dissertation

by

RICHARD JAMES HOFFPAUIR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2010

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Ralph Wurbs
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ABSTRACT

Daily Time Step Simulation with a Priority Order Based Surface Water Allocation Model. (December 2010)

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Chair of Advisory Committee: Dr. Ralph Wurbs

Surface water availability models often use monthly simulation time steps for reasons of data availability, model parameter parsimony, and reduced computational time. Representing realistic streamflow variability, however, requires modeling time steps with sub-monthly or daily temporal resolution. Adding daily time step simulation capability to the Water Rights Analysis Package (WRAP) and the Texas Water Availability Modeling (WAM) System is a growing area of need and interest in water rights permitting, water supply planning, and environmental protection.

This research consisted of the following tasks:

1. Key modeling issues are identified that are relevant to daily time step modeling, but are otherwise not considered with monthly simulations. These key modeling issues include disaggregating monthly naturalized flows into daily flows, routing changes to flow through the stream network, reducing impacts to water availability in a priority order based water right system through the use of streamflow forecasting, distributing water right targets from monthly

to daily amounts, and integrating flood control reservoir operations into the existing conservation reservoir modeling framework.

2. Two new programs for WRAP are developed to address the key daily time step modeling issues. The new programs include a pre-processor program, DAY, and a daily simulation program, SIMD.
3. A case study of the Brazos River Basin WAM is presented using daily time steps with SIMD. The purpose of the case study is to present an implementation of the daily modeling capabilities.
4. The case study simulation results are used as a basis to draw conclusions regarding monthly versus daily simulation outcomes.

The research, as presented through the Brazos River Basin WAM case study, illustrated that incorporating realistic daily streamflow variability into the simulation of a priority order based water allocation system can substantially affect the results obtained for time series of critical period reservoir storage contents, the determination of long-term water right reliability, and the distribution of unappropriated and regulated flows. The modeling capabilities developed by this research advance the state of water availability modeling with sub-monthly time steps by addressing the key modeling issues related to streamflow variability and routing.

DEDICATION

To my wife, Leslea, and our daughter, Abigail

and to my parents, Elizabeth and James

ACKNOWLEDGEMENTS

I owe a great amount of thanks and appreciation to Dr. Ralph Wurbs, my advising professor, chair of my advisory committee, and career mentor. He has offered unlimited and invaluable support, guidance, and patience over the years. I also want to thank my committee members: Dr. Tony Cahill, Dr. Francisco Olivera, and Dr. Andrew Klein.

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Thank you also to the many other graduate students and professors who have helped me over the years in various ways.

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CHAPTER I
INTRODUCTION

Technical evaluation of surface water right applications and the exercise of existing rights according to the doctrine of prior appropriation are essential components for managing the surface water supply of the State of Texas. New surface water right applications or amendments to existing surface water rights are evaluated by the Texas Commission on Environmental Quality (TCEQ) using the Water Availability Modeling (WAM) System. TCEQ maintains input data files covering all Texas river basins and all existing water rights therein. The Water Rights Analysis Package (WRAP) is a generalized computer model for simulating surface water rights through a period of naturalized hydrology (Wurbs 2010a). WRAP, basin-specific input files, geographic information system (GIS) tools, and auxiliary software and databases comprise the WAM System (Wurbs 2005a). The Texas Water Development Board (TWDB) and the Regional Water Planning Groups (RWPG) modify the WAMs to estimate surface water supply for the entire state using a 50-year planning horizon.

The focus of this research is the development of modeling capabilities within WRAP that allow for daily time step simulation. Key daily time step modeling issues addressed by this research are discussed in Section 1.3. A modeling implementation of the research is presented in this dissertation

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This dissertation follows the stle of the *Journal of Water Resources Planning and Management*.

through a daily simulation case study that uses the TCEQ WAM input files for the Brazos River Basin and San Jacinto-Brazos Coastal Basin. Based on the results presented through the case study, recommendations for building input datasets and selection of key daily time step modeling features are provided in the final chapters of this dissertation. The recommendations are provided so that this research can advance the field of surface water availability modeling in Texas and in other regions that employ a priority order based water allocation modeling system.

The research has progressed through several years of daily time step model development, revisions, and refinements. The evolution of the WRAP daily time step modeling capabilities have been, and will continue to be, documented in chapters contained in the published versions of a user's manual for the expanded WRAP modeling system. The manual is titled *Conditional Reliability, Sub-Monthly Time Step, Flood Control, and Salinity Features of WRAP* (Wurbs 2010c). This manual is also known, and is hereafter referred to, as the *Supplemental Manual*. Specific details and requirements for model input record coding that are not covered in this dissertation are, however, provided in the *Supplemental Manual*.

The term *sub-monthly* refers to any time step covering less than one month. The WRAP modeling capabilities created for this research are capable of simulating hydrology and water rights with any time step equal to one day up to one month. The default sub-monthly time step for the new modeling capabilities within WRAP is one day. References to a daily modeling time step and a sub-monthly modeling time step are used interchangeably throughout this dissertation.

1.1 Background

A surface water right is the authorization to use the waters belonging to the state. Water rights in Texas are administered according to the doctrine of prior appropriation, which is based on the tenet of "first in time, first in right" (Wurbs 1995). Water rights authorized first are known as senior rights. Water rights authorized at a later date are known as junior rights. The relative ranking of water rights according to their time of authorization is intended to protect more senior rights from impairment by newer or more recently authorized rights. Quantitative estimates of available water supply for new water right applications or amendments to existing applications are made through the use of the WAM System by the TCEQ as a constituent of the larger process for evaluating new surface water rights. The generalized WRAP computer model adheres to the doctrine of prior appropriation in the simulation of water rights.

1.1.1 Water Rights Modeling in Texas

Unappropriated streamflows are a key output of water availability models and represent the flows in the river that are available for appropriation by new water rights. All existing water rights are simulated as diverting or impounding the amount of water to which they are legally entitled. Water rights are simulated in their relative priority order. New water rights are simulated as having access only to unappropriated streamflows in order to protect water availability to all existing and senior water rights.

In 1968 the Texas Water Commission (TWC), a predecessor agency of the TCEQ, began development of a water availability model (Wurbs and Walls 1989). The model was composed of computer programs and data files for simulating water rights across the state. The model was utilized and improved primarily within the agency through the 1980s. Output data from previous simulations were used along with other available information in the evaluation of new permit applications through the late 1990s.

Drought conditions in Texas prompted the state legislature to pass Senate Bill 1 in 1997, also known as the Brown-Lewis Water Management Plan. Article VII of the 1997 Senate Bill 1 required the development of new water availability models for the state's river basins. The WAM System replaced the legacy water availability model output data for the technical evaluation of surface water permit applications and for preparation of planning studies (Wurbs 2001). WRAP was chosen as the simulation model for the WAM System.

1.1.2 Water Rights Analysis Package

Development of a generalized river and reservoir model began at Texas A&M University (TAMU) under the direction of Dr. Ralph Wurbs in the late 1980s (Wurbs and Walls 1989). TAMUWRAP developed around a monthly time step simulation of the Texas water permitting system. The model was the early prototype that evolved over time into WRAP. Continued research and development through the 1990s allowed for the incorporation of more features and flexibility in modeling a wide variety of water right types and special conditions (Wurbs and Sanchez-Torrez 1996; Wurbs 1997).

WRAP is a generalized model and can be applied to any river basin or particular reservoir or water right system. Input files particular to Texas river basins are developed for the TCEQ WAM. WRAP-SIM is the simulation program within the WRAP suite of programs. SIM simulates water resources management of a single basin or multiple basins using a priority order system through a period of homogenous or naturalized hydrology. WRAP-TABLES is the post-processor program for organizing and analyzing output from SIM. (Wurbs 2010a)

1.1.3 TCEQ Water Availability Modeling System

The WRAP suite of programs, WRAP-SIM input datasets of all surface water rights for every river basin of the state, GIS tools, and auxiliary software and databases comprise the WAM System (Wurbs 2005a). The WRAP-SIM input datasets are maintained by the TCEQ. Figure 1.1 shows the area coverage of the 21 WAM datasets that cover the 23 river and coastal basins of the state. Each basin-specific dataset contains a period of hydrologic data, water rights, and control points where the hydrology and water rights are located. The hydrologic data are time series of monthly naturalized streamflow volumes and net reservoir evaporation-precipitation depths at primary control points within the model. The hydrologic data cover a period of record typically from the early 1940s through late 1990s. SIM contains methods for distributing the hydrologic data from primary control points to the control points where input hydrology is not provided. Water right inputs are any data that describe water right permits, reservoirs, water right systems, or any special conditions associated with water right permits.

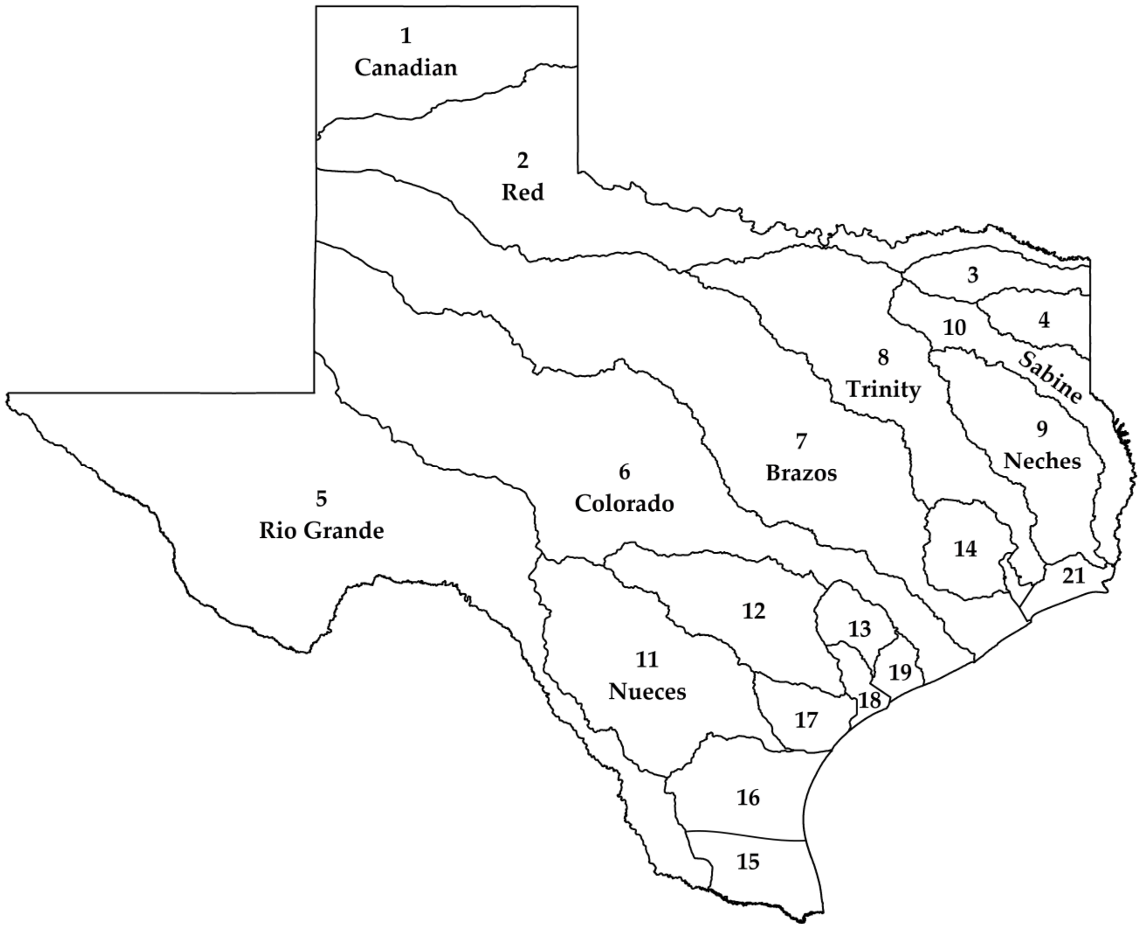

Figure 1.1 WAM System River Basins

TCEQ maintains two alternative sets of WAM input files for each river basin. The Full Authorization scenario input files assume water rights are exercised according to the full authorization contained in their respective permits or certificates of adjudications. As such, water rights are assumed to completely consume the water of their right unless the permit specifically requires a discharge. Reservoirs are modeled with storage capacity equal to the permitted amount without consideration of sedimentation. Only permanent water rights are included in the Full Authorization input files. The Full Authorization scenario is used by TCEQ in the evaluation of new permanent water right applications or in the evaluation of amendments to existing permanent water rights. Modified versions of the Full Authorization scenario are also the base datasets used for state water planning purposes by TWDB. Table 1.1 lists the period of record, number of primary and total control points, number of water right (WR) and instream flow (IF) records, and number of reservoirs in the Authorized Use WAMs.

Table 1.1 Texas WAM System Authorized Use Datasets

Map No.	River Basin	Period of Record	Primary Control Points	Total Control Points	Model Water Rights	Model Reservoirs
					WR/IF	
1	Canadian River Basin	1948 - 98	12	85	56/0	47
2	Red River Basin	1948 - 98	47	447	489/103	245
3	Sulphur River Basin	1940 - 96	8	83	85/5	53
4	Cypress Bayou Basin	1948 - 98	10	189	163/1	91
5	Rio Grande Basin	1940 - 00	55	957	2,584/4	113
6	Colorado River Basin and Brazos-Colorado Coastal	1940 - 98	45	2,395	1,922/86	511
7	Brazos River Basin and San Jacinto-Brazos Coastal	1940 - 97	77	3,842	1,634/122	678
8	Trinity River Basin	1940 - 96	40	1,334	1,169/23	703
9	Neches River Basin	1940 - 96	20	318	333/17	176
10	Sabine River Basin	1940 - 98	27	376	310/21	207
11	Nueces River Basin	1934 - 96	41	542	373/30	121
12	Guadalupe and San Antonio River Basins	1934 - 89	46	1,349	860/184	237
13	Lavaca River Basin	1940 - 96	7	185	71/30	22
14	San Jacinto River Basin	1940 - 96	16	411	148/13	114
15	Lower Nueces-Rio Grande	1948 - 98	16	119	70/6	42
16	Upper Nueces-Rio Grande	1948 - 98	13	81	34/2	22
17	San Antonio-Nueces	1948 - 98	9	53	12/2	9
18	Lavaca-Guadalupe Coastal	1940 - 96	2	68	10/0	0
19	Colorado-Lavaca Coastal	1940 - 96	1	111	27/4	8
20	Trinity-San Jacinto	1940 - 96	2	94	24/0	13
21	Neches-Trinity Coastal	1940 - 96	4	245	138/9	31

The Current Conditions scenario is the second set of input files maintained by TCEQ for each basin. The Current Conditions scenario assumes water rights divert only according to the maximum amount over the previous 10 years. Many water rights throughout the state do not currently divert up to their fully authorized diversion amounts. Major reservoirs are modeled according to a current elevation-capacity-surface area survey to reflect the current conditions of sedimentation. Term permits in addition to permanent water rights are included in the Current Conditions scenario. The Current Conditions scenario is used by TCEQ to evaluate term water right applications. Table 1.2 lists the period of record, number of primary and total control points, number of WR and IF records, and number of reservoirs in the Current Conditions WAMs.

Table 1.2 Texas WAM System Current Conditions Datasets

Map No.	River Basin	Period of Record	Primary Control Points	Total Control Points	Model Water Rights	Model Reservoirs
					WR/IF	
1	Canadian River Basin	1948 - 98	12	85	56/0	47
2	Red River Basin	1948 - 98	47	450	486/110	246
3	Sulphur River Basin	1940 - 96	8	83	85/5	53
4	Cypress Bayou Basin	1948 - 98	10	189	159/1	91
5	Rio Grande Basin	1940 - 00	55	957	2,594/4	113
6	Colorado River Basin and Brazos-Colorado Coastal	1940 - 98	45	2,396	1,928/93	510
7	Brazos River Basin and San Jacinto-Brazos Coastal	1940 - 97	77	3,852	1,734/145	711
8	Trinity River Basin	1940 - 96	40	1,338	1,190/35	709
9	Neches River Basin	1940 - 96	20	318	317/21	198
10	Sabine River Basin	1940 - 98	27	375	314/21	206
11	Nueces River Basin	1934 - 96	41	545	392/32	125
12	Guadalupe and San Antonio River Basins	1934 - 89	46	1,352	879/202	243
13	Lavaca River Basin	1940 - 96	7	184	68/30	21
14	San Jacinto River Basin	1940 - 96	16	413	156/15	114
15	Lower Nueces-Rio Grande	1948 - 98	16	119	70/6	42
16	Upper Nueces-Rio Grande	1948 - 98	13	81	39/2	23
17	San Antonio-Nueces	1948 - 98	9	53	12/2	9
18	Lavaca-Guadalupe Coastal	1940 - 96	2	68	12/0	0
19	Colorado-Lavaca Coastal	1940 - 96	1	111	27/4	8
20	Trinity-San Jacinto	1940 - 96	2	94	26/1	13
21	Neches-Trinity Coastal	1940 - 96	4	245	138/9	31

1.2 Literature Review

This research covers several areas of water resources simulation modeling. Those areas include the consideration of model time step size, disaggregation of flows to smaller time steps, and streamflow routing. A review and comparison of generalized river/reservoir models is included.

1.2.1 Model Time Step Size

Xu and Singh (1998) reviewed the history and applications of monthly water balance models, which date back to the 1940s. With the advent of computers and data availability, monthly water balance models gained widespread use. Although daily or sub-daily models could be used for hydrologically relevant computations such as reservoir yield analysis, effects of land use and climate change or the creation of streamflow records at ungaged locations, monthly time step models are less data intensive and typically have fewer parameters to select or calibrate. Parameter parsimony alone may lead model users to choose a monthly model over one with a smaller time step. Minimizing the number of model parameters can improve the correlation of model output to the parameter values selected.

Estimates of reservoir firm yield can be sensitive to the temporal resolution of the input data. Montaseri and Adeloye (1999) used a statistic known as reservoir critical drawdown period to estimate the required time step of the input data for reservoir management models. Reservoir critical drawdown period is the length of time a particular reservoir experiences the range of storages from full to empty. The authors noted that most reservoirs require monthly or shorter term data to accurately model their critical period drawdown behavior. Fennessey (1995) compared the effect of daily, monthly, and yearly hydrological time series on reservoir yield sensitivity. He found that monthly model input data slightly over-predicts firm yield as compared to daily data. However, the difference decreases as reservoir storage capacity increases, which may be associated with longer critical drawdown periods.

Knighton and Nanson (2001) examined the variability of flow events with respect to drainage area and upstream-to-downstream location within the basin. The authors examined events with single, multiple, and compound hydrograph peaks. The authors noted the implication of event duration on water supply and accessibility. Events with sub-monthly duration, particularly those with a single hydrograph peak, may have a lower water supply value in upper portions of the basin. Attenuation with distance downstream may increase the flow event duration and improve accessibility for water supply.

1.2.2 Streamflow Disaggregation

A major task during input data development for water availability modeling is the creation of naturalized hydrology. Naturalized hydrology is the amount of water that would have been present in the stream network in the absence of human activity. The typical approach to developing sequences of naturalized flow is to obtain or estimate the time series of reservoir storages and withdrawals, river diversions, and return flow discharges over the gaged flow period of record. Additions or subtractions to the gaged streamflow record to remove the human introduce changes. The process of naturalizing a streamflow record can be subjective and often conducted with monthly time steps (Wurbs 2001). It is often impossible and impractical to adjust for all historical water management practices, as such data usually do not exist. Monthly time steps reduce data uncertainty due to imprecise records and upstream-to-downstream travel times.

Using daily time steps in a water availability model requires either direct input of daily naturalized hydrology or a method to distribute monthly flow volumes into daily flows. The process of distributing flow from monthly to daily sequences is referred to as disaggregation. Disaggregation methods tend to be either statistically based or based on replicating patterns from real-world flow time series. Statistically based methods of disaggregation seek to replicate sub-monthly streamflow variability while preserving monthly total volume.

Kumar et al. (2000) developed an algorithm for disaggregating flows from monthly to daily time steps at multiple locations on the same drainage network. A key feature of their algorithm is the preservation of intersite flow patterns. Linear programming was used to optimize statistical parameters that generate the minimum absolute error at multiple locations. A single solution for disaggregated daily flows was generated as opposed to other common statistical methods based on autoregressive or Markov chain models.

Disaggregating flows from monthly to daily volumes can be accomplished by duplicating patterns from daily gaged flow records. Hughes and Smakhtin (1996) presented a method using flow duration curves from gaged locations to patch or extend daily flow records. A flow duration curve is an empirical representation of the percentage of time a particular flow rate is equaled or exceeded during a period of a streamflow record (Vogel and Fennessey 1995). Smakhtin (2000) extended the flow duration curve method by estimating daily flow duration curves at ungaged locations using monthly flow data. Pattern duplicating methods such as the flow duration curve method can be applied without the need to calibrate statistical parameters.

1.2.3 Streamflow Routing

In general, routing is a process of tracing quantities from a source through a network system to a destination location. Chow et al. (1988) defined streamflow routing as "a procedure to determine the time and magnitude of flow at a point on a watercourse from known or assumed hydrographs at one or more points upstream." Flow routing is often referred to as flood routing because it is most commonly associated with tracing the progress of flood waves along stream channels. In the case of WRAP, routing is applied to the trace of flow depletions or returns. The routed changes to flow are used to adjust the naturalized flow in WRAP.

A commonly used method for flow routing is the empirical Muskingum method (Chow et al. 1988). The theoretical basis for the method is the continuity equation, which states that changes in channel storage between two points are a function of the inflow at the upstream point and outflow at the downstream point. Approximating the differential equation with respect to time as discrete measurements of channel flow at different times, the present outflow at the downstream point can be expressed as a linear combination of the present inflow at the upstream point and the previous time step measurements of inflow and outflow. The method requires the calibration of two empirical parameters, K and X. These parameters can be calibrated from streamflow records.

Calibration of the Muskingum parameters assumes there is no lateral inflow between the upstream and downstream points. In order to calibrate K

and X, a method for removing or circumventing the lateral inflows is required. Nathan and McMahon (1990) and Spongberg (2000) described the separation of baseflow and quick flow in a streamflow time series using an equation borrowed from signal processing. The authors apply a digital filter to separate the two flow types. Baseflow hydrograph separation between points on a stream channel is a common method for removing incremental flow. Using a digital filter can be a helpful means to automate this process when dealing with a large number of streamflows. Another approach is to use a modified Muskingum method that assumes incremental flows occur between two points on the stream reach and these incrementals are proportional to the inflow at the upstream point. O'Donnell (1985) and Khan (1993) developed a three-parameter Muskingum method, whereby an additional empirical parameter α captures the contribution of incremental flow.

1.2.4 Generalized River/Reservoir System Models

The following literature review covers several generalized river/reservoir modeling systems. Many generalized modeling systems are used throughout the world for water resources management, systems operations and optimization, and short- and long-term supply planning. The models reviewed in this section include the U.S. Army Corps of Engineers (USACE) Southwestern Division (SWD) Reservoir System Simulation Model (SUPER), the USACE Hydrologic Engineering Center (HEC) Reservoir System Simulation (ResSIM), the River and Reservoir Operations (RiverWare), and the Generalized River Basin Network Flow Model (MODSIM). These models, including WRAP, are representative of the modeling systems commonly used in Texas by water resources planning and management agencies. (Wurbs 2005b)

SWD SUPER Modeling System

The SUPER model was developed by USACE SWD and used by the Dallas, Fort Worth, Tulsa, and Little Rock district offices. The SUPER model simulates the multi-purpose reservoir systems with a daily time step including the hydrologic and economic impacts (Hula 1981). SUPER can be used with a long time series of daily hydrology. Results of the simulation include stage or discharge hydrographs for each reservoir and river control points. Economic benefit functions may be used along with the hydrology results. Streamflow input to the model is based on the uncontrolled sub-watersheds at each control point. The streamflows are routed between control points using the Muskingum method. The primary application of the model is to simulate daily streamflows under various operating policies in support of flood control operations (Wurbs 2005b).

HEC-ResSIM Modeling System

HEC-ResSIM is the USACE HEC replacement system for the HEC-5 Simulation and Flood Control and Conservation Systems model. The initial version of the HEC-5 model was released in May 1973. ResSIM has three modules for managing data and executing the model. The modules include Watershed Setup, Reservoir Network, and Simulation. ResSIM is capable of decision and operations support for reservoir control as well as supporting reservoir planning studies. The model operates with a time step of 15 minutes up to 1 day. ResSIM's output data include time series of streamflows, reservoir storages, and evaporation. Routing of streamflows can be performed with a variety of methods including coefficient, Muskingum, Muskingum-Cunge, modified Puls methods, and SSARR routing methods. (Wurbs 2005b)

RiverWare Modeling System

RiverWare is a generalized river/reservoir modeling system developed and maintained at the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CADWES). RiverWare can be applied to water supply planning, reservoir system operations, and water right evaluations. RiverWare has three simulation environments, including a conventional simulation for physical processes, a rule-based simulation for user-specified operating rules, and an optimization environment for application of linear programming solutions. Model time steps can vary from hourly to monthly. (Wurbs 2005b)

MODSIM

MODSIM is a generalized river/reservoir system and network flow model developed at Colorado State University. MODSIM is used to simulate priority order based water allocation (Labadie et al. 2000). MODSIM can be used to simulate instream flows and instream flow requirements, run-of-river diversions, reservoir diversions, and multiple-reservoir system operations. Conjunctive use of surface water resources with groundwater resources can be modeled by linking MODSIM with groundwater models. Model time steps include daily, weekly, or monthly time steps (Wurbs 2005b).

Modeling System Characteristics

Each of the modeling systems in the review above provide flexibility and generalized options for modeling complex river/reservoir systems. The models, however, utilize different algorithms and computational structures. Common algorithms for river/reservoir modeling systems include linear programming (LP), network flow programming, and ad-hoc algorithms. LP involves finding an optimal solution to a linear objective function subject to constraints. LP boundary constraints are typically given as inequalities. Network flow programming is a type of LP in which the solution space is described in terms of combinatorial or interconnected linkages. Ad hoc algorithms are any algorithms designed specifically for a model or for solving a particular problem. Ad hoc algorithms are often embedded within a larger LP model. Tables 1.3 and 1.4 are reproduced from Wurbs. (2005b)

Table 1.3 Structure of the Alternative Modeling Systems

Model	Organizing Computational Structure
SUPER	Ad hoc simulation computations progressing from upstream to downstream
ResSIM	Object-oriented ad hoc simulation progressing from upstream to downstream
RiverWare	Object-oriented options for pure and rule-based simulation and optimization
MODSIM	Object-oriented based on network flow programming
WRAP	Ad hoc simulation progressing in order of user-defined priorities

Table 1.4 Characteristics of the Alternative Modeling Systems

Model	Programming Language	Computational Method	Simulation Time Step	Graphical User Interface	Graphics	Cost
SUPER	Fortran	ad hoc	day	no	no	free
ResSIM	Java	ad hoc	15 min. to day	yes	yes	free
RiverWare	C++	ad hoc/LP	hour to year	yes	yes	proprietary
MODSIM	C, C++	LP	day, week, month	yes	yes	free
WRAP	Fortran	ad hoc	day, sub-monthly, month	yes	no	free

1.3 Research Objectives

The objective of this research is the development of modeling capabilities that address key daily time step issues in a flexible and robust manner while still meeting the requirements of a priority order based modeling paradigm. WRAP is a generalized modeling system that can be applied to any river and reservoir system. The new modeling capabilities of this research must also integrate with and expand the modeling combinations that are possible with the existing WRAP capabilities. The following modeling issues were addressed in the research and development of the WRAP daily simulation model, SIMD, and the WRAP pre-processor program, DAY. The specific modeling capabilities that were implemented within SIMD and DAY to address the following key issues are the subject of Chapter II.

1.3.1 Disaggregation of Naturalized Streamflow

WRAP-SIM performs simulations with a monthly time step. A monthly time step may represent adequate temporal resolution during conditions of low naturalized flow variability at sub-monthly time scales. Naturalized flow in most Texas river basins, however, regularly exhibits high degrees of flow variability over the course of any month. Flow events that occur at sub-monthly time scales cannot be represented and evaluated with monthly simulation time steps. Such events may include extreme low flow periods, which have implications for aquatic habitat and water quality, as well as high flow events, such as storm flow pulses or overbanking flood flows. Whereas the monthly aggregation of flow volume may indicate sufficient instream flow being available to support aquatic habitat, an actual daily time series of streamflow could reveal little to zero flow present for a portion of the month. Similarly, monthly flow aggregation allows sub-monthly peaks of excess water availability resulting from high flow events to be applied to water right demands at any time during the month.

Making use of the existing monthly naturalized streamflow datasets, particularly those developed for the Texas WAM System, is an essential component to implementing daily time step simulations. The existing monthly naturalized flow datasets were developed through extensive data gathering and adjustments to historical gaged streamflow time series. The existing monthly naturalized flow datasets have also been used as a hydrologic basis for many years of surface water permitting and planning in Texas. Maintaining monthly volumetric equivalence between monthly and daily simulations through the use of the monthly naturalized streamflow datasets will allow for direct comparisons between monthly and daily time step simulations.

Developing methods of the monthly to daily naturalized streamflow disaggregation in SIMD requires that multiple alternative methods be provided to address various levels of data availability. At ungaged locations in the WAM, only the monthly naturalized flow may be available with little or no daily streamflow data. Disaggregation may have to be conducted using a simple uniform distribution of flow to each day of the month, or statistical methods might be utilized to allow for the representation of flow variability. Nearby gaged streamflows might be useful as a source of pattern for disaggregation. Other locations in the basin may have little to no water management infrastructure within the upstream watershed. Daily gaged flows at such locations might represent nearly naturalized conditions and could be used as direct daily streamflow input.

Disaggregating streamflow from monthly to daily sequences may have significant implications for simulated water availability. Monthly total flows mask the daily peaks and troughs in the hydrograph. Within any particular month, flows may vary greatly from day to day. The choice of disaggregation will affect the sub-monthly streamflow variability that is represented during the simulation. Sub-monthly streamflow variability may affect the simulated ability of water rights to meet their monthly total target demands. The potential effects of the choice of disaggregation method on water availability are explored in this dissertation.

1.3.2 Routing Changes to Flow

Streamflow travel time and wave attenuation are typically considered with daily to sub-daily time intervals. At monthly time steps, individual flow events are not easily differentiated unless the upstream and downstream locations are far apart and the difference in flow events is large. Occasionally, high flow events are recorded at the end of a month at an upstream location and at the beginning of the next month at a far downstream location. However, daily time steps are generally necessary for streamflow travel time and wave attenuation to be represented in the simulated hydrology.

The method of disaggregating monthly to daily naturalized flow will determine if travel time and wave attenuation are realistically represented in the simulation. Daily flows derived from uniformly distributing monthly flows by the number of days per month will not contain any more streamflow travel time or wave attenuation information than represented in the total monthly flow sequences. Using realistic daily flow patterns to disaggregate monthly naturalized flow will embed the effects of streamflow routing in the naturalized hydrology. Realistic daily flow patterns for disaggregation must be utilized at successive downstream locations for streamflow routing to have a meaningful effect on the simulation.

WRAP streamflow is represented as total flow at control points. Only changes to flow are cascaded downstream through the control point network. In a single monthly time step, SIM cascades the changes to streamflow caused by water rights through all downstream control points until reaching the basin outlet. This method of cascading changes to streamflow is consistent with the representation of streamflow in monthly total volumes. Individual flow events are not represented with respect to travel time and wave attenuation with monthly time steps. However, if realistic daily flow patterns are utilized, the changes to flow caused by water rights should cascade downstream with the same travel time and the same attenuation as the underlying streamflow. The travel time to the basin outlet may span several days or weeks, depending on the distance and average stream gradient. A method to route changes to flow downstream is therefore required in SIMD.

1.3.3 Forecast Simulation

Routing changes to flow downstream potentially introduces time lag between when the change is made and when the change in flow passes the location of senior water rights before exiting the stream network at the basin outlet. Priority order access to available water is a fundamental concept in WRAP. The time lag created by routing thereby presents a complexity for adherence to priority order access. The changes to streamflow by junior rights can potentially affect the water availability of senior rights for many subsequent future time steps until exiting the stream network.

Reducing the potential for the effects of routing to circumvent priority order access to available water is a major research area for SIMD development. The approach taken is to proceed with the simulation beyond the current time step, record water availability information in future time steps, and then return to the current time step and constrain water availability in a manner that reduces future impacts to senior rights. The method of forward simulation is known in SIMD as forecasting and is discussed further in Chapter II. Key areas of research for the forecast simulation include determination of the metrics of future water availability to apply to junior rights in the current time step, how far into the future to simulate, and which rights to consider in the forecast simulation.

1.3.4 Water Right Target Demand Distribution

Water rights in SIM develop monthly targets of water demand. These targets must be distributed to daily target demands in SIMD. Whereas monthly targets are applied against monthly streamflows in SIM, the monthly target must be applied against daily flows in SIMD. Uniformly distributing the monthly target by the number of days per month is an option in SIMD.

If the daily naturalized streamflows were disaggregated using realistic daily flow patterns, water availability may vary greatly over the course of a month. Water availability shortages occur when the target demand is greater than the available water. An area of research in SIMD is developing a method for non-uniform monthly to daily target distribution with the possibility for shortage recovery during times of greater water availability within the month. Non-uniform target distribution and intra-month shortage recovery are possible methods for dealing with the daily streamflow variability introduced by pattern disaggregation.

1.3.5 Flood Control

Extreme high flow events can be represented in a daily time step simulation. An important feature of water management for extreme high flow events is reservoir flood control operations. An area of research in SIMD includes developing the capability to model flood control operations. Flexibility in SIMD is required for flood control reservoirs to integrate with the existing conservation storage reservoirs represented in the WAM datasets or as independent and separate flood control only reservoirs. Another area of research in SIMD is utilizing streamflow forecasting for flood control to mitigate future downstream flows that exceed established flood discharge limits.

1.4 Scope and Organization of the Dissertation

Chapter II reviews the programs in WRAP that were developed by this research. Emphasis is given to the capabilities in DAY and SIMD that address the key modeling issues described in Section 1.3. Specific details and requirements of the input records for DAY, SIMD, and the daily time step post-processing jobs of TABLES are provided in the *Supplemental Manual*. TABLES is a separate WRAP program for simulation output post-processing. It was not developed by this research but supports post-processing of SIMD output.

The case study chosen is the WAM dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, Bwam. The primary WAM dataset for this dissertation is the Full Authorization scenario, Bwam3. Within the Bwam dataset, only those control points, water rights, and reservoirs located in the Brazos River Basin are considered in the simulation output. The Brazos River Basin and San Jacinto-Brazos Coastal Basin are shown in Figure 1.2. The Current Conditions scenario, Bwam8, is examined only for the effects of return flows in a daily simulation.

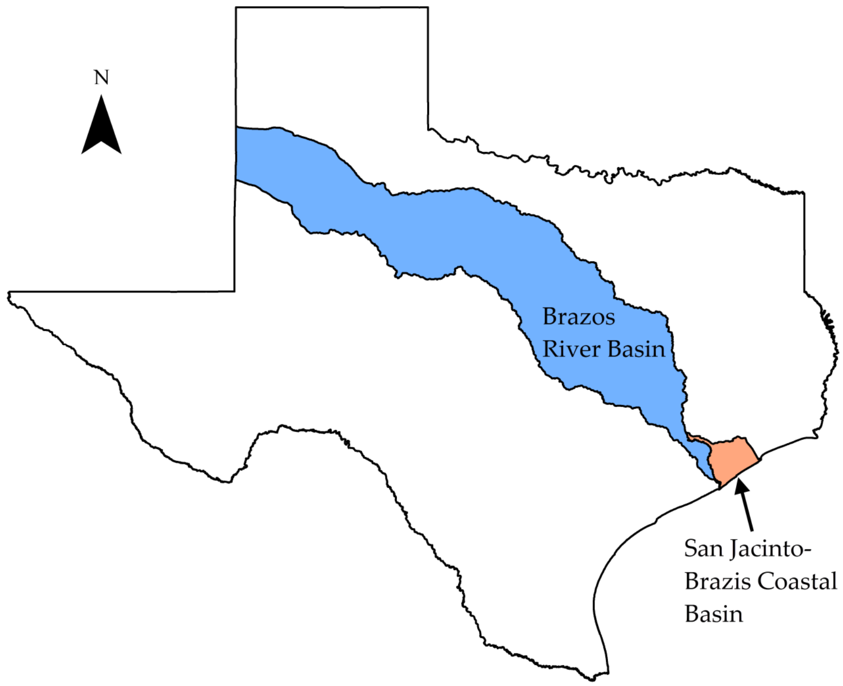

Figure 1.2 Brazos River Basin and San Jacinto-Brazos Coastal Basin

The purpose of the case study is to present an implementation of the modeling capabilities developed by this research and to explore the various alternative configurations and parameterizations that are possible with SIMD. Chapter III focuses on developing daily input data for the case study. The TCEQ WAM dataset and the SUPER daily unregulated streamflow data for the Brazos River Basin are described. As discussed in Chapter III, the SUPER daily unregulated flows are used as input data for deriving routing parameters and daily streamflow patterns for the simulation studies in Chapters V and VI. USACE flood control reservoir pools in the Brazos River Basin and the corresponding downstream streamflow flow gages are described. These data are used to construct input for the flood control simulations.

Chapter IV presents the methods of disaggregation, routing, water right forecasting, water right target setting, and flood control forecasting that are utilized in the case study simulations. Multiple alternative SIMD methods and parameter settings are described. The goal of the case is not to derive a single or optimum set of SIMD methods or parameters for general WAM application. The case study is organized and presented to highlight the research and development of DAY and SIMD, and to provide insight into the sensitivity and appropriateness of the various methods and parameter settings of SIMD.

Chapters V and VI contain case study simulation results with emphasis on water availability and flood control, respectively. Chapter V is organized into sections that individually focus on time step size, disaggregation methods, routing placement, forecasting, and target demand distribution. Chapter VI is organized into sections that focus on flood flow forecasting periods, the effects of flood control on water availability, and regulated streamflow.

Chapters VII and VIII are summary chapters. Chapter VII summarizes the findings of the case study and provides guidance for applying the findings of this research to other WAM datasets. Input data construction, the effects of various methods and parameter settings on water availability, and the effects of flood control operations are discussed. Chapter VIII reviews the modeling methods developed by this research with respect to the effectiveness in addressing the key modeling issues described in Section 1.3.

CHAPTER II

DAILY TIME STEP FEATURES OF WRAP

The conventional WRAP modeling system is documented in the *Reference Manual* (Wurbs 2010a) and *Users Manual* (Wurbs 2010b). The simulation model, WRAP-SIM, uses a monthly time step. The *Supplemental Manual* (Wurbs 2010c) documents additional features within the WRAP modeling system including the programs WRAP-DAY, WRAP-SIMD, and the post-processing jobs within WRAP-TABLES that support SIMD. SIMD allows each of the 12 months of the year to be subdivided into multiple time intervals, with the default being daily. A conventional monthly time step simulation may be performed with SIMD with the same input datasets used with SIM. Supplemental SIMD input data are added to the primary simulation input data (DAT) file to activate the daily modeling features. Additional daily hydrology data are provided in the daily simulation control point input file (DCF), which is read exclusively by SIMD.

Datasets used in SIM can be modified to simulate in daily time steps in SIMD with only the addition of the sub-monthly job control (JT) record in the DAT file. The default settings will apply to all aspects of the daily modeling features such as the disaggregation of monthly naturalized flows into daily flows and the calculation of daily demand targets. While the default settings allow for easy conversion from monthly to daily simulation, most river basins have hydrologic characteristics and water management practices that are unlikely to be adequately represented without additional input data and application of additional water management features within SIMD. The steps taken to develop a daily simulation dataset for the Bwam case study in this dissertation are likely to be similar for most river basins with high daily flow variability, multi-day travel times to the outlet, and many water users arranged in a priority-order-based management system.

Options are provided in the post-simulation program TABLES for developing frequency relationships using either daily time step simulation results or aggregated monthly results. The program DAY contains routines for calibration of flow routing parameters for use in SIMD and the same flow disaggregation methods as SIMD for developing sequences of naturalized flows or flow patterns for input to SIMD.

Sections 2.1, 2.2, and 2.3 briefly introduce the three WRAP programs that support daily time step modeling. DAY and SIMD are entirely new programs and were developed by this research. TABLES is an existing WRAP program that supports post-processing of SIMD output. Sections 2.4 through 2.8 discuss in further detail how the key modeling issues of Section 1.3 are addressed by this research. A variety of modeling capabilities were researched and developed in DAY and SIMD that are necessary to facilitate sub-monthly time step simulation. Capabilities such as forecasting are specific to sub-monthly time step simulation within a priority order based water allocation model.

2.1 WRAP-DAY

A significant portion of the effort in constructing a monthly simulation dataset for SIM is likely to be devoted to creating naturalized flows. Similarly, much of the effort in developing additional data for the daily SIMD simulation is likely to be related to daily hydrology. Daily flows used as direct input or as pattern input in SIMD should be representative of the expected flows in the absence of the water management scenario being simulated. Therefore, in most cases, the daily flows should be as representative of naturalized conditions as possible. The daily flows are provided as input to SIMD in the form of daily flow (DF) records in the DCF file. DAY can be used to facilitate the testing of monthly to daily flow patterns as well as the organization of daily flows into DF record format.

DAY can calibrate streamflow routing parameters between one or more upstream gages and a common downstream gage. Unlike monthly time steps, simulation of a stream network with daily time steps requires the consideration of the time between when change in flow is made and the time and amount when that change arrives at downstream locations. DAY calibrates the routing parameters from the daily flows used as DF record input for SIMD. The calibrated routing parameters are likewise used as input in SIMD on control point routing information (RT) records in the DCF file. However, SIMD does not apply the routing parameters to the flows from the DF records. Routing within SIMD is only applied to changes in flow. DAY can calibrate, and SIMD will apply, the values of lag and attenuation or the values of K and X from the Muskingum routing methods.

Routing parameters are calibrated in DAY for the period of record represented by the DF records. SIMD uses the period of record routing parameters to route changes to flow caused by WR record water rights. SIMD can also use the period of record routing parameters to route the changes to flow caused by flood control reservoir (FR) record flood control rights. Alternatively, DAY can be used to calibrate routing parameters for those time steps in the DF period of record that correspond to flood flow conditions. The flood flow routing parameters can be used by SIMD to route changes to flow caused by the FR record flood control rights.

2.2 WRAP- SIMD

Key modeling issues relevant to modeling with daily time steps are discussed in Section 1.3 of this dissertation. The following features of SIMD were developed by this research to address the key modeling issues:

- routines for setting the number of daily computational time steps contained in each month and subdividing monthly naturalized flow volumes into daily time steps;
- options for setting and varying diversion, hydropower, and instream flow targets over the daily time steps within each month;
- option for reading daily naturalized flows from an input file;
- alternative options for disaggregating naturalized monthly flows to daily time intervals;
- options for determining current day available streamflow for WR record water rights based on a forecast simulation over a future forecast period specified for individual water rights;
- forecast of the remaining channel capacity defined by flood flow limit (FF) records and used by flood control reservoir (FR) records for flood control operations;
- alternative methods for routing of streamflow adjustments; and
- aggregation of daily simulation results to monthly values and recording of simulation results at daily and/or monthly time steps.

The inputs for daily simulation in SIMD are divided between the common DAT input file shared with SIM and a DCF input file utilized only by SIMD. These records and their placement in the respective input files are detailed in Appendix A of the *Supplemental Manual*. The DAT file contains records specifying daily job control, water right daily target setting, and building options and flood control operations. The DCF file contains routing parameters, disaggregation methods, daily flow records, and optional placement of the water right daily target records.

2.3 WRAP-TABLES

The program TABLES can process any SIMD output using the job 2 routines available for processing the conventional monthly SIM output files. Output data in SIMD can be aggregated and written to the conventional output (OUT) file that is identical in format to a SIM OUT file. TABLES has jobs available to process daily output contained in the SIMD-specific sub-monthly output (SUB) file and the peak annual flood flow (AFF) file. TABLES job 6 routines are identical to the job 2 routines, except that the SUB file is used as input instead of the OUT. TABLES job 7 routines read and process the AFF file. The TABLES jobs are discussed in more detail in Appendix C of the *Supplemental Manual*.

2.4 Disaggregation Methods

The Texas WAM System contains datasets of monthly naturalized flows. Disaggregation options are adopted in SIMD when applying daily time steps. Selecting and applying the disaggregation options is a subjective process of making optimal use of available monthly and daily flow data. Historical gaged daily flow records and daily data related to past water management are required to convert gaged flows to naturalized or unregulated flows but may be limited in availability. The effects of lag and attenuation on flow can complicate the process of naturalizing gaged flows and transferring them to ungaged sites. Converting gaged daily flows to naturalized daily flows at pertinent locations is difficult for extensively developed river basins.

SIMD reads monthly flow volumes from the naturalized inflow (IN) records contained in the naturalized flow (FLO) file or the Hydrologic Engineering Center (HEC) Data Storage System (DSS) file for primary control points and distributes the flows to secondary control points using parameters from the flow distribution (DIS) file in the exact same manner as SIM. These monthly flows are then disaggregated to daily amounts in SIMD. The alternative disaggregation methods all convert sequences of monthly naturalized flow volumes into daily flow volumes that preserve the monthly amounts. Preservation of the total monthly naturalized flow volume at each control point is particularly relevant when comparing SIM and SIMD simulation results.

Three disaggregation methods are reviewed in the following sections. The methods include the uniform distribution method, the linear spline interpolation method, and the daily flow pattern method. Other methods of disaggregation that are variations of the uniform, linear interpolation, and flow pattern methods are available in SIMD. However, the case study only focuses on application of the three base disaggregation methods mentioned here.

2.4.1 Uniform Distribution

The uniform distribution option consists of computing daily flow volumes by dividing the monthly naturalized flow volume by the number of sub-intervals in the month. This option produces the least daily flow variability of all the disaggregation options available in SIMD. For a location with no available information on flow variability, or a location with known low variability in flow, the uniform disaggregation option may be adequate as a default disaggregation option until actual daily flow data or information about flow variability at the location can be collected.

2.4.2 Linear Spline Interpolation

Linear spline interpolation may be applied to a sequence of monthly naturalized flows to obtain non-uniform daily sequences within each month. The methodology is illustrated graphically in Figure 2.1. Instantaneous flows at the beginning, middle, and end of each month of the series are defined based on the flow volumes in the preceding, current, and subsequent months. The straight lines connecting these points are called linear splines. The splines represent instantaneous flow rates at points in time, and the areas under the splines represent flow volumes during intervals of time. The splines define areas representing monthly flow volumes, which are dissected at sub-monthly intervals to disaggregate the monthly volumes into sub-monthly volumes.

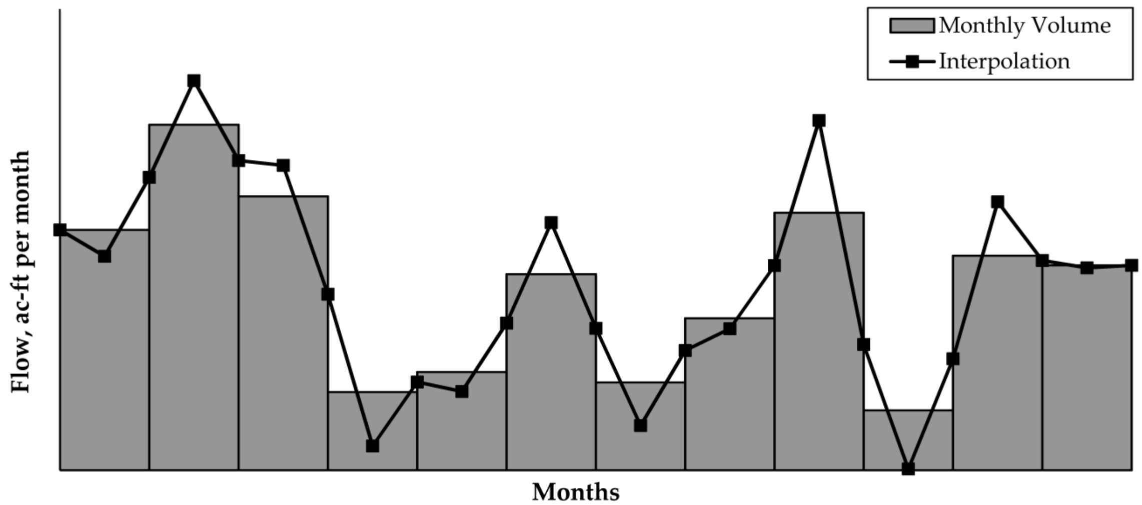

Figure 2.1 Example of the Linear Spline Interpolation Method of Disaggregation

The shaded bars in Figure 2.1 represent the monthly naturalized flow volumes that are to be disaggregated. The linear interpolation splines connect the beginning, middle, and ending points of each month. The end of one month is the beginning of the next month. The spline flows at the beginning and end of each month are set as the average of the mean instantaneous flow rates associated with the monthly volumes of adjoining months. Middle-of-month flow points are then set based on conserving the total monthly flow volume. The middle-of-month flow point is selected such that the monthly flow volume being disaggregated is represented by the area under the two linear splines spanning that month.

In some cases, with beginning/end-of-month flow points set as averages of adjacent mean monthly flows, the preservation of the monthly volume by defining a single middle-of-month point may result in negative middle-of-month flow rates. When such a negative flow occurs, two zero-flow points are set within the month defining a period of zero flow during the middle of the month that results in preservation of the total volume for the month without creating negative flows. A zero monthly volume results in a zero instantaneous flow rate for the entire month.

The linear interpolation method for disaggregating monthly flows to daily volumes results in smoother and more serially correlated daily flow sequences than the actual observed daily flows. Thus, the linear interpolation method may be best applied to streams that are baseflow dominated with rare high flow pulses. In streams with high variability, the linear interpolation method may have better results for the low variability baseflow periods than for pulse flow periods.

2.4.3 Normalized Flow Pattern

A sequence of daily flow volumes defining a pattern of naturalized or unregulated variability may be compiled external to SIMD and input on the DF records. The DF record pattern flow sequences may cover the entire hydrologic period of record or some other period that may be much shorter. The flow pattern is repeated as necessary within the SIMD simulation to extend over the entire hydrologic period of record as defined in the DAT file.

Disaggregation of monthly naturalized flow volumes according to the flow pattern method proceeds in the following manner. The daily flow pattern sequences from the DF records are summed on a monthly basis. The daily flow pattern sequences for a particular month are divided by their respective summed value. Division of the daily flow pattern by their summed value creates a daily sequence of normalized coefficients for each month. The monthly naturalized flow sequences are disaggregated to daily naturalized flow sequences by multiplying by the daily sequence of normalized coefficients for each month.

Figure 2.2 shows an example of the uniform, linear interpolation, and flow pattern disaggregation methods for one year of daily flows. Each sequence contains an equivalent monthly naturalized flow volume. Daily flow variability within each month differs with respect to the disaggregation method. Lower daily flow variability toward the end of the year shown in the figure allows less deviation on a daily basis between the three methods.

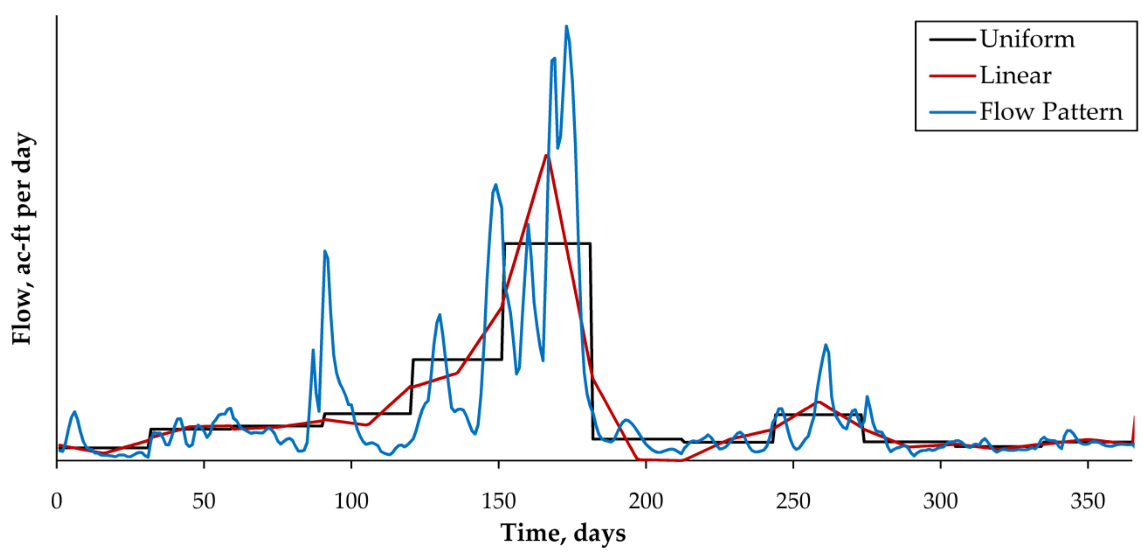

Figure 2.2 Example of Uniform, Linear Interpolation, and Daily Flow Pattern Disaggregation

2.5 Routing Parameters

Daily simulation time steps necessitate consideration of the travel time of changes to flow in WRAP. Control point flow is represented on a total volume basis and is not simulated as traveling between control points. Only changes to flow are cascaded downstream through the control point network. In large river basins, the travel time to the outlet from various points in the basin may be several days to several weeks.

Changes to flow created by WR record water rights are routed using the first set of routing coefficients on the RT records. Changes to flow created by FR record flood control reservoirs can optionally be routed using the same set of routing coefficients. Alternatively, changes to flow created by FR record flood control reservoirs may be routed using the second set of routing coefficients on the RT record. Whereas changes to flow from WR record rights will likely occur throughout the simulation's period of record and during all flow conditions, changes to flow as a result of flood control reservoirs are likely to occur during periods of high flow. Therefore, DAY can calibrate and SIMD can utilize a set of routing parameters that are representative of all flow conditions versus a set of routing parameters that are representative of high flow conditions.

2.5.1 Parameter Calibration in DAY

DAY offers five objective functions to use in the calibration of routing parameters. Objective function 1 computes the root of the mean squared error between the routed hydrograph and the measured hydrograph at the downstream location for all time steps in the calibration. Objective function 2 computes the mean absolute error between the routed and measured hydrographs. Objective function 3 computes the mean absolute error in daily lateral inflow volume. Objective function 4 is a weighted average of objective function 1 and objective function 3. Objective function 5 is a weighted average of objective function 2 and objective function 3. The calibration routine in DAY seeks to minimize the value of the objective function specified by the user.

Calibration of routing parameters for all flow conditions is typically performed with objective functions 2 or 5. The parameters selected by DAY in the calibration routine provide an optimized minimum value of the mean absolute error in lateral inflow volume plus the mean absolute error. Minimizing absolute errors in objective function 3 allows lower flow conditions nearer to the central tendency of the flow regime to contribute meaningfully to the objective function value.

Calibration of the routing parameters for high flow conditions is typically performed with objective functions 1 or 4. Squared errors tend to favor the minimization of the objective function for peak flow events. Therefore, objective functions 1 and 4 are more suited for calibrating routing parameters to be used for high flow conditions. High flow conditions are identified for any time step in which the flow at the upstream end of the reach exceeds a flow criteria provided by the user. The calibration routine steps through every time step in the input dataset. However, only those time steps that meet the upstream flow threshold are used to compute the objective function value.

2.5.2 Routing in SIMD

Travel time and the effects of attenuation are characterized with flow routing parameters in SIMD. Routing occurs between two control points, if and only if routing parameters are provided for the upstream control point of the river reach. In the absence of routing parameters for a river reach, the routing methods in SIMD are not activated during the simulation. On reaches without routing, changes to flow entering the upstream end of the reach will equal the changes to flow exiting the downstream end of the reach each day less any channel losses.

SIMD allows the choice of the lag and attenuation method and an adaptation of the Muskingum method for routing changes to flow. Both approaches have analogous input parameters related to travel time and storage attenuation that are best determined through calibration. In addition to being used to route changes to flow as a result of WR record water rights, flow routing parameters can be specified that only apply to the changes in flow caused by flood control reservoirs.

Routing parameters are provided as input on the RT records. The RT records are placed in the DCF file before the DF records. The routing parameters are applied in every time step of the simulation. Consequently, the parameters should be given as a best fit for flow conditions over the entire period of record.

2.5.3 Placement of Routed Changes to Streamflow

Changes to flow from previous days may require several days to weeks to completely travel to the outlet of the basin. This is particularly relevant in the Brazos River Basin, where tributaries extend for several hundred miles upstream of the Gulf of Mexico. Changes to flow can be placed within the priority sequence at the priority date of the water right. Alternatively, changes to flow can be placed at the beginning of the priority sequence. Changes to flow from WR record rights are placed according to the sub-monthly job options (JU) record parameter WRMETH. Changes to flow from FR record flood control rights are placed according to JU record parameter FRMETH.

Changes to flow from previous days can be routed at the beginning of each daily time step using JU record option WRMETH 1. This allows the previous changes to flow to affect water availability for all water rights in the basin until the changes to flow exit the basin's outlet. The alternative option, WRMETH 2, is to route the changes to flow at the priority order in which the original depletion was made. Only the water right making the depletion and all junior water rights will experience a direct impact to water availability as the changes to flow travel to the outlet.

Placing routed changes to flow at the beginning of the priority order ensures that all water rights factor past streamflow depletions into their respective calculations of available water. Present-day depletions can be limited by streamflow depletions from past days as they propagate downstream. This self-limiting feedback from the use of WRMETH 1 reduces the likelihood of over-appropriation of the stream.

With WRMETH option 2 selected in JU record field 6, streamflow depletions for each individual water right are routed within the priority sequence, thus protecting senior rights from earlier actions of junior rights. However, forecasting is still required to prevent over-appropriation of the same water where senior rights incorrectly appropriate flows that have already been appropriated by junior rights in previous days.

2.6 Forecasting

Forecasting addresses the issue of water control and use decisions today that affect downstream available and regulated flows over the next several days. Time is required for changes to flow to propagate downstream to the river system outlet. The lag time may be several days to weeks for large river basins. Water supply diversions and return flows and multiple-purpose reservoir operations in the current time step affect downstream available and regulated flows in subsequent time steps. The SIMD forecasting algorithms for WR record rights protect downstream senior water rights from the actions of upstream junior rights in the current and preceding days. Forecasting for flood control reservoir operations is based on making no release today that contributes to downstream flooding today or during future days.

Flow forecasting in SIMD is defined as considering streamflow availability over a future forecast period, F_P, when determining water availability and flood flow capacity for each individual water right in the priority-based water rights computation loop. Alternative methods can be selected on the JU and daily water right data (DW) records for adjusting current time period water availability based on information related to future downstream streamflow availability or future downstream senior water right shortages. Without forecasting, SIMD considers only the current time period in determining water availability and flood flow capacity. With forecasting, F_P future days are considered in the examination of available flows or senior shortages at downstream control points. Forecasting is not relevant for water rights at a control point that has no other control points located downstream.

Forecasting is activated by setting a forecast period. The F_P may be assigned to any, none, or all WR record water rights and FF record control points. Forecasting options for WR record water rights are selected by JU and DW record parameters. A global forecast period for all WR and FR record rights may be entered on the JU record. The global F_P is overridden for individual WR record rights by specifying an F_P on the DW record or for flood control rights on FF records. The value of F_P will be ignored for IF record and Type 3, 4, 5, and 6 WR record rights, which do not diminish downstream water availability. With no global or individual right F_P specified, the default is zero F_P, meaning no forecasting.

2.6.1 Forecast Simulation

A conceptual example of the structure of the SIMD forecast algorithm is presented in Figure 2.3 for a forecasting period of 5 days. Before the 10th day of the month is simulated, SIMD preserves all state variables. The simulation proceeds with a forecasting simulation that covers days 10 through 15. Day 10 of the forecast simulation is conducted so that the pertinent information of days 11 through 15 can be recorded from the forecast simulation. No information is recorded for day 10 of the forecast simulation. After completing day 15 of the forecast simulation, SIMD returns to day 10 of the real simulation. All state variables are initialized back to their values prior to the forecast simulation. Day 10 of the real simulation proceeds. Any water rights that use forecasting can access the array, which contains information regarding future downstream shortages, future water availability, or future regulated streamflow up to day 15.

The process is repeated when the real simulation completes day 10 and proceeds to day 11.

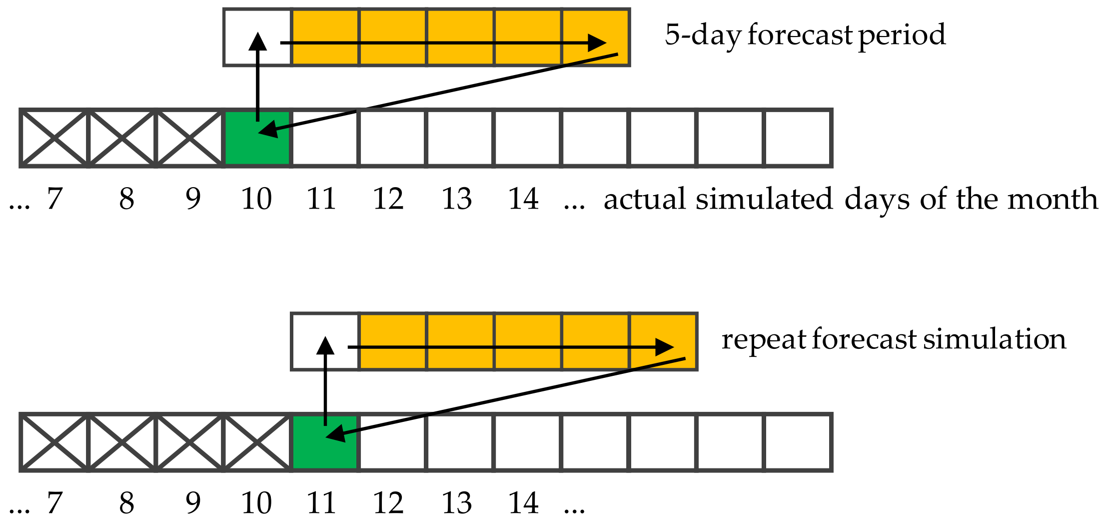

Figure 2.3 Conceptual Example of the SIMD Forecast Algorithm

2.6.2 Forecast Methods for Water Availability

SIMD provides two alternative general strategies for adjusting current time period available streamflow for WR record rights based on information recorded during the forecast simulation. Forecasting methods 1 through 5 are based on recording information during the forecast simulation related to shortages incurred by water rights. Forecasting methods 1, 3, and 5 use measurements of future downstream senior shortages as a quantity to reduce present-day water availability. Forecasting method 1 records the maximum of the daily totals of downstream senior shortages over the forecast period. Forecasting method 3 records the maximum shortage of any single downstream senior water right during any day of the forecasting period. Forecasting method 5 cancels water availability to the water right applying forecasting if any downstream senior water right experiences a shortage of any size during any day of the forecast period. Forecasting methods 2 and 4 are analogous to methods 1 and 3, respectively. However, methods 2 and 4 do not increase the measured downstream senior shortage by the amount of channel loss between the upstream rights and the downstream senior rights.

Forecasting methods 1 and 3 can limit water availability to water rights with downstream senior rights that experience future shortages. However, the limitation on water availability is with forecasting methods 1 and 3, which may not result in shortages for the upstream rights or perhaps only result in a partial shortage. For example, a downstream senior water right experiences 10 ac-ft of shortage during the forecast simulation, and the upstream junior water right has access to 1,000 ac-ft of available water in the current day. The 10 ac-ft reduction of water availability imposed by forecast methods 1 or 3 may not affect the upstream junior water right’s ability to meet the target demand of the current day. However, the use of forecasting method 5 would have changed the water availability of the upstream junior right from 1,000 ac-ft to 0 ac-ft.

2.6.3 Water Balance

Routed streamflow depletions affect flows at downstream control points in future days. Negative values may be generated in the control point flow availability array. SIMD sets these negatives to zero and adjusts the flow in the next time step to compensate. Thus, long-term volume balances are maintained, though the volume balance may be violated in individual time steps. JT record parameter NEGCP initiates output of the monthly totals of these daily negative flows to the message (MSS) file.

Over-appropriation occurs when upstream depletions in past days are routed downstream and encounter drier downstream future streamflow conditions. The primary cause is a mismatch in routing parameter values with the particular flow event under which the original depletion was made. WRMETH 2 also allows for over-appropriation when senior rights make streamflow depletions of water that was appropriated by upstream juniors in previous days.

WRMETH option 1 does not protect senior rights in the current day from actions of junior rights in previous days. WRMETH option 2 protects senior rights from the routed changes to flow from junior rights, but with imperfect routing and imperfect or no flow forecasting, it allows senior rights to take streamflow that has already been depleted by junior rights in previous days. Thus, the issue of over-appropriation may be increased with WRMETH option 2 if forecasting is not applied to protect the water balance. The case study will examine the efficacy of forecasting methods and forecasting periods to reduce the incidence of over-appropriation that is responsible for daily negative flows and subsequent days of water balance makeup.

Forecasting for downstream senior water shortages can be used with WRMETH 1 to protect the water availability of downstream senior water rights. Downstream senior rights can be affected directly by the routed changes to flow of junior rights in previous days with WRMETH 1. Forecasting for downstream senior water shortages also protects the water balance. Violations of the water balance and makeups in subsequent days can result in reduced water availability for water rights. Forecasting for downstream senior water right shortages, therefore, can protect the prior appropriation system and the water balance with the use of WRMETH 1.

Forecasting for downstream water availability is used with WRMETH 2 to protect the water balance. Since senior water rights are not directly affected by the routed changes to flow from previous days, forecasting for downstream water availability is the best forecasting method for use with WRMETH 2.

2.7 Target Demand Distribution

Monthly target demands are established by the annual WR record target demand and the associated use-coefficient (UC) record set. The monthly demand is distributed uniformly over each day of the month by default. SIMD offers the option to set the number of days (ND) in which the target demand can be met. If ND is greater than zero, the monthly target demand will be distributed in the first ND days of the month. After the first ND days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target-building process if the shortage recovery (SHORT) parameter option is activated. Use of ND and SHORT enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

Targets for water supply diversions, hydroelectric power generation, and environmental instream flow requirements are set in a SIMD daily simulation by combining selected options from the following three sets of target-building options.

1. A monthly target is determined at the beginning of each month in a SIMD daily simulation in the same manner as a SIM or SIMD monthly simulation. UC record use coefficients are combined with an annual target from a WR or IF record. The target may be adjusted further by water right backup (BU), target options (TO), supplemental options (SO), target series (TS), flow switch (FS), drought index (DI), and other supporting records as described in the *Reference* and *Users Manuals*.
2. The monthly target set in step 1 above is distributed over the days of the month using one of the following two alternative approaches as specified by parameters on JU and DW records:
   - uniform distribution; or
   - the specified number of days, ND, option with or without the shortage recovery, SHORT, option.
3. The daily target for a WR or IF record water right may be set or adjusted using options specified on DW and daily water right option (DO) records that are analogous to the BU, TO, SO, TS, FS, and DI record monthly target-setting options noted in step 1 above.

For most modeling applications, daily targets will be set for most water rights by combining options from the first two sets listed above. However, the third set of options is also available as needed.

2.7.1 Uniform Target Distribution

The monthly target is set at the beginning of the month as specified by a WR or IF record and accompanying UC, TO, SO, FS, DI, TS, and other optional auxiliary records. The monthly target is distributed over the days of the month based on either a uniform distribution or the features controlled by the ND and SHORT parameters as follows. A global default daily target distribution option may be set on the JU record. This default can be overridden for individual water rights by options activated by the daily water right data DW record associated with each individual water right. The JU and DW record default for the conversion of monthly to daily targets is the uniform distribution option described as follows. Monthly targets may be evenly divided into daily amounts. A monthly target is divided by the number of sub-intervals in each month to obtain amounts for each computational time step. With this option, a shortage occurs any time a daily target is not fully met.

2.7.2 Non-uniform Target Distribution

Options activated by the parameters ND and SHORT entered on the JU or DW record provide an alternative to the uniform distribution. The ND option allocates the monthly target to a specified ND number of days each month. The daily target amount during the ND days is the monthly target divided by ND. The period of ND days always begins in the first day of the month. The ND option may be combined with the SHORT option, which allows an attempt at recovering shortages from preceding days in subsequent days of the same month.

The parameter SHORT on the JU or DW record is a switch that activates an option used in combination with the ND option that allows diversion, hydropower, or instream flow shortages to be supplied in subsequent days of the same month. With the ND option, if the target is fully met during each of the first ND days of the month, the target is zero for the remainder of the month with or without the SHORT option. However, with the SHORT option, a failure to meet the full target amount during the first ND days results in an attempt to recover shortages in subsequent days of the same month if sufficient water is available.

The choice of ND is somewhat subjective without knowledge of the specific water right implementation. Furthermore, daily pumping limits for individual water rights should be checked before assigning a value of ND so that targets that would violate water right permit conditions are not built.

2.8 Flood Control

The daily time step features of SIMD are applied in modeling reservoir operations for flood control. Relatively small computational time steps are required to accurately model flood control operations due to the great fluctuations in flow rates over the short time spans that typically occur during flood events. SIMD uses a day as the smallest time step for simulation that can be used for modeling flood control operations of large river and reservoir systems. Smaller systems may require smaller time steps.

Flood control reservoir operations are treated as a type of water right in SIMD. Within WRAP, a water right is a set of water control requirements and associated reservoir facilities and operating rules. Flood control rights are activated by FR records and are simulated along with all other water rights activated by WR and IF records. The same reservoir may have any number of WR or IF record rights with associated conservation storage (WS) and operating rules (OR) records, and any number of FR record flood control rights.

The FR record, the FF record, and the flood volume and outflow (FV/FQ) record pair are the only SIMD input records specifically for flood control. These records are described in the *Supplemental Manual* in further detail. FR and FF records are used to model reservoir operations for flood control analogously to applying WR, WS, OR, and IF records to model operations for water supply, hydropower, and environmental instream flow requirements.

SIMD creates an optional output file with the filename extension AFF with annual series of peak flows and storages. The maximum naturalized flow, regulated flow, and storage volume are listed for each year of the simulation at specified control points. The SIMD AFF file is read by TABLES to perform flood frequency and damage analyses specified by a 7FFA record.

2.8.1 Reservoir Pools

In SIMD, a reservoir consists of any or all of the four pools shown in Figure 2.4. SIM includes only the bottom two pools. In either SIM or SIMD, inactive and conservation pool storage capacities are specified on storage WS records associated with WR records. SIMD allows controlled and uncontrolled flood control storage to be specified by FR records. A flood control pool defined by FR record fields 9 and 11 may include zones with outflows through either gated or ungated outlet structures. Pools governed by a gated structure in SIMD are referred to as controlled flood control pools. Pools governed by an ungated structure in SIMD are referred to as uncontrolled flood control pools.

The division of the flood control pool between controlled and uncontrolled storage pools is defined by FR record field 10. Both portions of the flood control pool are optional. Releases from the lower controlled portion of the flood control pool are constrained by streamflow limits entered on FF records. Releases from the upper uncontrolled pool are defined completely by the FV/FQ record storage-outflow table.

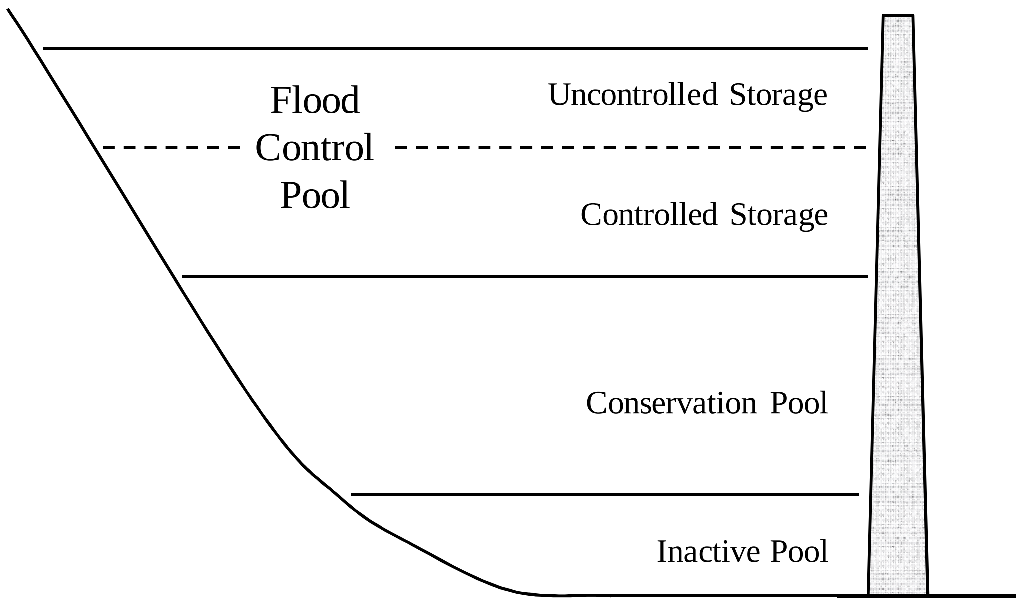

Figure 2.4 Reservoir Pools Defined by SIMD WS and FR Records

2.8.2 Reservoir Operations

Reservoir operations for either flood control or conservation storage purposes in SIM or SIMD consist of either storing inflows or making releases. WR record rights can fill storage to the top of the conservation pool only. FR record rights can fill storage to the top of the flood control pool. However, if the conservation pool is not full when an FR record stores inflows, the empty conservation space is filled as the storage level rises into the flood control pool. The optional FR record field 7 parameter, FCDEP, controls whether downstream control points are considered in computing the amount of streamflow available for filling flood control pools. With the default FCDEP option, the control point flow availability computation is applied in the conventional manner and all downstream control points are considered. The alternative FCDEP option is to store all regulated flow at the control point of the dam, with the exception of releases from conservation storage to downstream water rights. Releases from the controlled flood control pool are governed by operating rules defined by parameters entered on the FR and FF records. Uncontrolled outflows are governed by the FR and FV/FQ records. The routed changes to streamflow as a result of storing inflows or making releases can be made at the priority dates specified on the FR record, or the changes to streamflow may be routed prior to the priority sequence. The JU record field 7 parameter, FRMETH, controls the placement of routed changes to streamflow from the flood control pools.

2.8.3 Forecasting for Regulated Flows

The SIMD forecast simulation can record future downstream senior shortages or downstream future water availability for use with curtailing current-day water availability for WR record rights. The forecast simulation can also record future regulated flow in the absence of future releases from controlled flood control storage at the location of the FF record rights. Forecasted regulated flow at the location of the FF record rights is used in conjunction with the FR record operating rules to begin impounding streamflow in controlled flood control storage. Forecasting can also reduce the amount of water released from controlled flood control storage. By adopting a forecast period on the FF record rights, the SIMD modeling approach generally provides a conservatively higher estimate of the amount of water to be stored in controlled flood control storage to reduce to the extent possible the amount of regulated flow at the location of the FF record rights. Due to approximations related to forecasting and routing, water may be stored in greater quantities and for longer periods of time than necessary. However, future days extending past the forecast period are not considered in reservoir operating decisions. Routed reservoir releases could contribute to flooding at downstream control points in future days after the end of the forecast period. Approximations related to imperfect forecasting and routing are an issue in modeling reservoir operations as well as in actual real-world reservoir operations.

2.8.4 Flood Control Routing

Changes to flow are routed downstream in SIMD using the first set of routing parameters listed on the RT records in the DCF file. These routing parameters are applied to changes to flow made by WR or IF record rights. Changes to flow made by FR record flood control reservoirs can be routed using the same routing parameters used by WR and IF record rights, or the second set of routing parameters on the RT record can be used exclusively for flood control routing.

Changes to flow created by FR record flood control reservoirs can be routed within the priority sequence at the priority of the underlying FR record. Alternatively, changes to flow can be routed prior to the priority sequence. The latter option exposes all senior rights to the effects of the flood control reservoir. This may, in some instances, have a beneficial effect on water availability. Flood control releases may proceed for many days or weeks after a flood event. The addition of flood control releases to the stream at the beginning of the priority sequence can provide enhanced water availability for WR record rights. Placement of the changes to flow created by the FR record flood control reservoirs is set by JU record parameter FRMETH.

CHAPTER III

INPUT DATA FOR THE BRAZOS WAM CASE STUDY

Chapter III introduces the case study for this research. The portion of the case study covered in this chapter relates to development of daily input data for the Bwam dataset. Chapter III is organized in the following manner. Section 3.1 introduces the Brazos River Basin and Bwam dataset. Section 3.2 introduces the source of daily flow patterns, and then a comparison of the daily flow patterns on a monthly basis to the Bwam monthly naturalized flows is presented. These daily flow patterns will be used in Chapter IV to develop routing parameters and serve as a data input for the flow pattern disaggregation method. Section 3.3 presents the nine USACE flood control reservoirs for the Brazos River Basin and the corresponding flood flow gages downstream of these reservoirs. The USACE system of flood control reservoirs and flood flow gages are used as a basis for constructing the flood control input records in Chapter IV.

3.1 Brazos River Basin and Bwam Dataset

The Brazos River is the longest river in the state of Texas. The headwaters begin in New Mexico and continue across the state until ultimately emptying into the Gulf of Mexico. The total drainage area of the basin is approximately 45,000 square miles, of which approximately 42,000 square miles lie within Texas. Large portions of the drainage area near the headwaters, however, are not hydrologically connected to the remainder of the basin.

The largest holder of reservoir conservation storage in the Brazos River Basin is the Brazos River Authority (BRA). In 1929, the Texas Legislature created the BRA as a state agency for the purpose of developing and managing the water resources of the Brazos River Basin. The BRA holds conservation storage rights in nine USACE reservoirs, including Whitney, Waco, Aquilla, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville. The USACE operates these nine reservoirs for flood control purposes and contracts with BRA for water supply from the conservation pools. BRA also owns and operates Lakes Possum Kingdom, Granbury, Limestone, and Alan Henry.

The Bwam dataset is the basis for the case study of this research. In particular, only those control points and water rights within the Brazos River Basin WAM downstream of Possum Kingdom Lake are considered in the case study. This includes all control points and water rights along the Little River and other tributaries connecting to the main stem of the Brazos River below Possum Kingdom Lake. The selection of this subset of control points and water rights from the Bwam dataset is related to daily flow pattern data availability and will be discussed in subsequent sections of this chapter.

The Bwam dataset for the Authorized Use scenario contains 3,842 control points, 1,634 water rights, and 678 reservoirs. Figure 3.1 shows the control points of the Bwam dataset for the Authorized Use scenario (Bwam3). Of the 3,842 control points, 77 control points have monthly naturalized inflow sequences provided as input in the SIM naturalized FLO input file. The period of record for the Bwam dataset is January of 1940 through December of 1997. Within this period of record is a major basinwide drought beginning in the late 1940s. The drought ceased basinwide with a major flood event in April and May of 1957. The firm yield of most reservoirs in the Brazos River Basin is defined over the 1950s' drought of record. Though the Authorized Use scenario dataset contains

678 reservoirs, there are 673 actual reservoirs represented in the model. Two of the basin reservoirs, Lakes Whitney and Waco, are modeled as multiple component reservoirs. Table 3.1 provides a summary of the reservoir conservation storage represented in the Bwam dataset for the Authorized Use and Current Conditions scenarios (Bwam8). The majority of conservation storage is held in reservoirs with 10,000 acre-feet (ac-ft) or greater of authorized storage capacity. The authorized water right demands with access to the conservation storage of these 37 reservoirs equals about 60.2% of the total 2,437,338 ac-ft per year water right demand represented in the Bwam3 DAT file.

Table 3.1 Reservoirs in the Brazos WAM

Individual Reservoir Conservation Storage Capacity (ac-ft)	Authorized Use (Bwam3)		Current Conditions (Bwam8)	
	Number of Reservoirs	Cumulative Reservoir Capacity (ac-ft)	Number of Reservoirs	Cumulative Reservoir Capacity (ac-ft)
less than 50	249	4,510	269	4,974
50 to 99	83	5,920	90	6,407
100 to 499	197	45,373	210	48,246
500 to 999	49	35,503	51	36,841
1,000 to 4,999	46	96,572	51	110,980
5,000 to 9,999	12	94,479	10	76,849
10,000 to 49,999	18	463,298	19	511,698
50,000 to 99,999	7	421,066	3	174,621
100,000 to 499,999	10	2,171,092	9	1,943,444
greater than 500,000	2	1,360,839	2	1,113,087
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Total	673	4,698,652	714	4,015,865

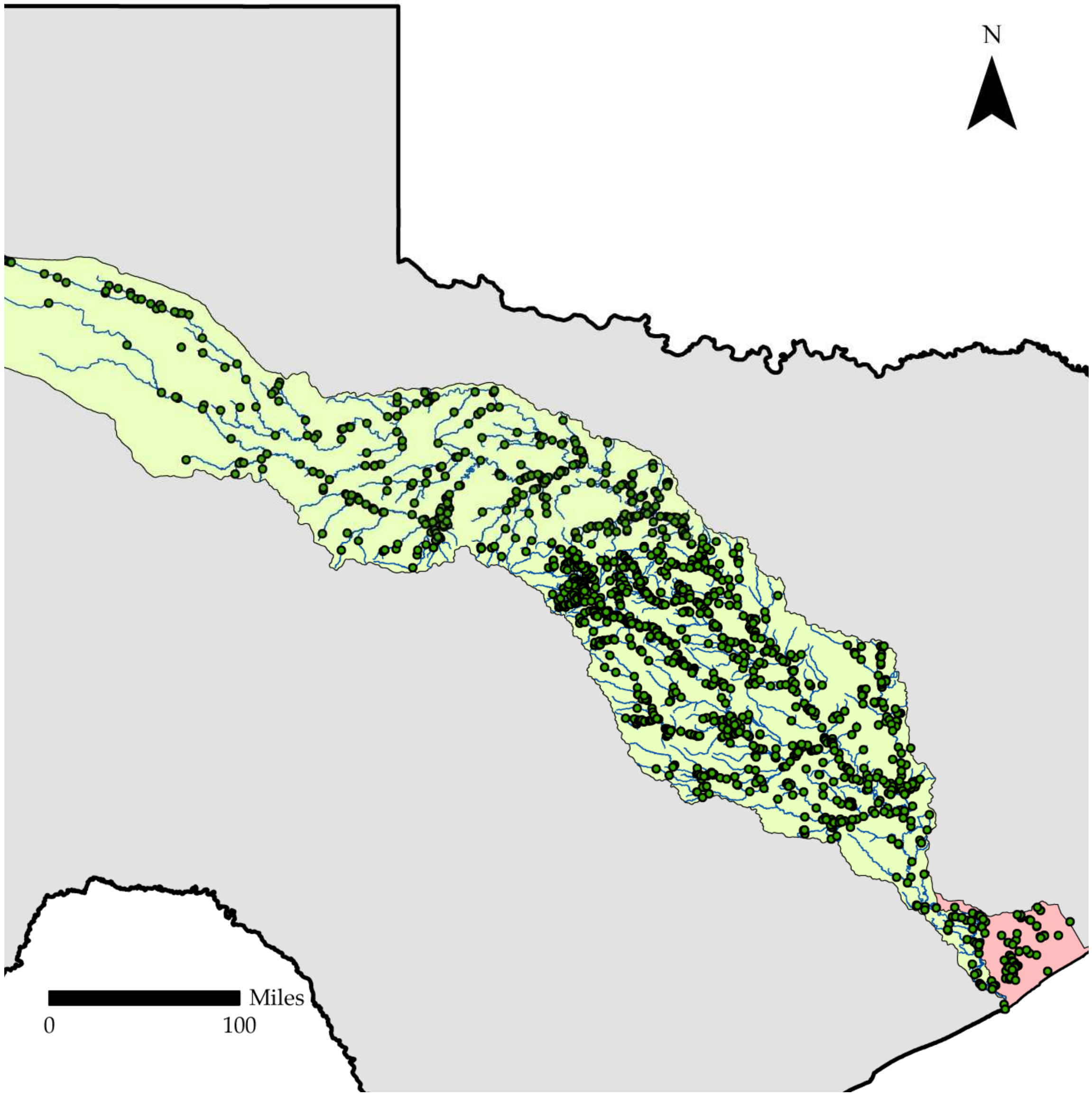

Figure 3.1 Control Points in the Bwam Dataset for Authorized Use

3.2 USACE SUPER Daily Unregulated Flow

The SUPER model is a computer program utilized by the USACE Fort Worth District for the simulation of a multi-purpose system of reservoirs over a long period of record. The streamflow inputs in SUPER are the unregulated flows that result from drainage areas uncontrolled by the system reservoirs represented in the simulation. Removing the effects of major reservoirs from the streamflow time series produces a time series that is significantly different from the gaged flow time series. However, the unregulated flows may contain the effects of minor run-of-river water rights and minor tributary on-channel dams.

Daily unregulated flows from the SUPER dataset are used as a pattern to disaggregate the Bwam monthly naturalized flows. The SUPER flow data cover the Bwam monthly naturalized period of record from 1940 through 1997. Spatially, the locations of the SUPER flow data cover points along the main stem of the Brazos River at and downstream of Possum Kingdom Lake including major tributaries. Table 3.2 gives the locations of SUPER flow data and the Bwam control points coincident at the SUPER locations. Figure 3.2 shows the map locations of the SUPER flow data. Figure 3.3 shows the relative locations of Bwam control points with SUPER flow data and their connectivity.

The SUPER flow data do not cover the San Jacinto-Brazos Coastal Basin in Bwam. The control points in the San Jacinto-Brazos Coastal Basin will utilize the uniform distribution method for disaggregation of their respective WAM monthly naturalized flow sequences into daily naturalized flows.

Table 3.2 Locations of USACE SUPER Flow Data and Corresponding Bwam Control Points

Name of the SUPER Flow Time Series	Control Point Identifier	Brazos WAM WAM Upstream Drainage Area, sq. miles	WAM Stream Length to Basin Outlet, miles
Possum Kingdom Outflow	515531	14,093	706
Grandbury Outflow	515631	16,181	559
Whitney Outflow	515731	17,690	462
Aquilla Outflow	515831	254	458
Bosque Outflow	227901	710	490
Waco Outflow	509431	1,655	428
Proctor Outflow	515931	1,280	639
Belton Outflow	516031	3,568	442
Stillhouse Outflow	516131	1,313	441
South Fork Outflow	SGGE55	132	430
Georgetown Outflow	516231	247	432
Granger Outflow	516331	726	399
Somerville Outflow	516431	1,008	271
Limestone Outflow	516531	675	351
Dennis	BRDE29	15,733	605
Glen Rose	BRGR30	16,320	527
Elm Mott	CON070	18,313	434
Clifton	NBCL36	977	468
Waco (Brazos)	BRWA41	20,065	418
Highbank	BRHB42	20,900	358
Gatesville	LEGT47	2,379	519
Lampasas Mouth	CON095	1,511	426
Little River	LRLR53	5,266	419
Georgetown	GAGE56	404	427
Rockdale	CON102	1,357	373
Cameron	LRCA58	7,100	357
Bryan (Brazos)	BRBR59	30,016	290
Yegua Mouth	CON129	1,302	257
Washington	CON147	33,930	234
Easterly	NAEA66	936	334
Bryan (Navasota)	NABR67	1,427	300
Navasota Mouth	CON231	2,241	240
Hempstead	BRHE68	34,374	202
Richmond	BRRI70	35,454	97

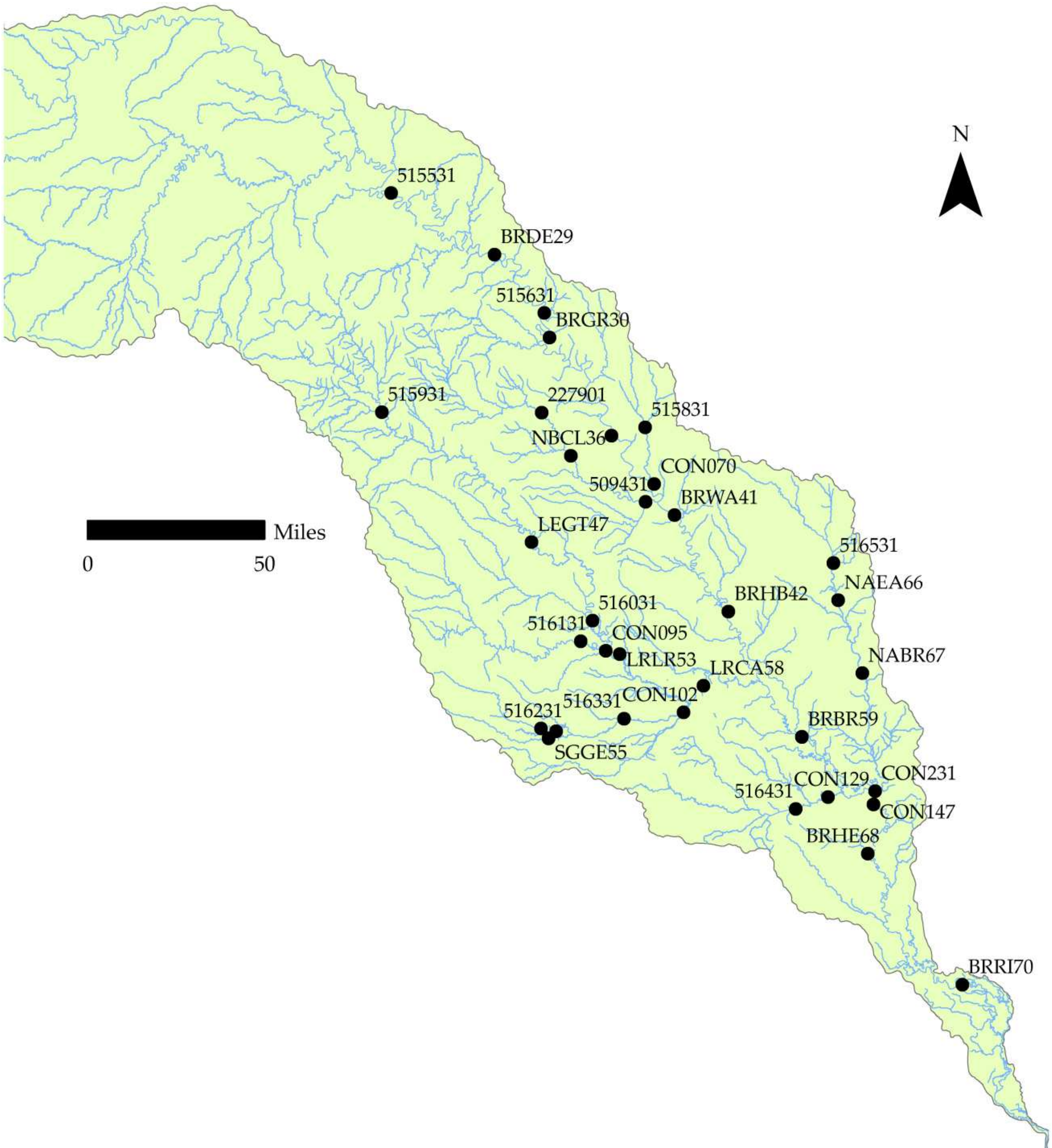

Figure 3.2 Bwam Control Points Corresponding to Locations of USACE SUPER Flow Data

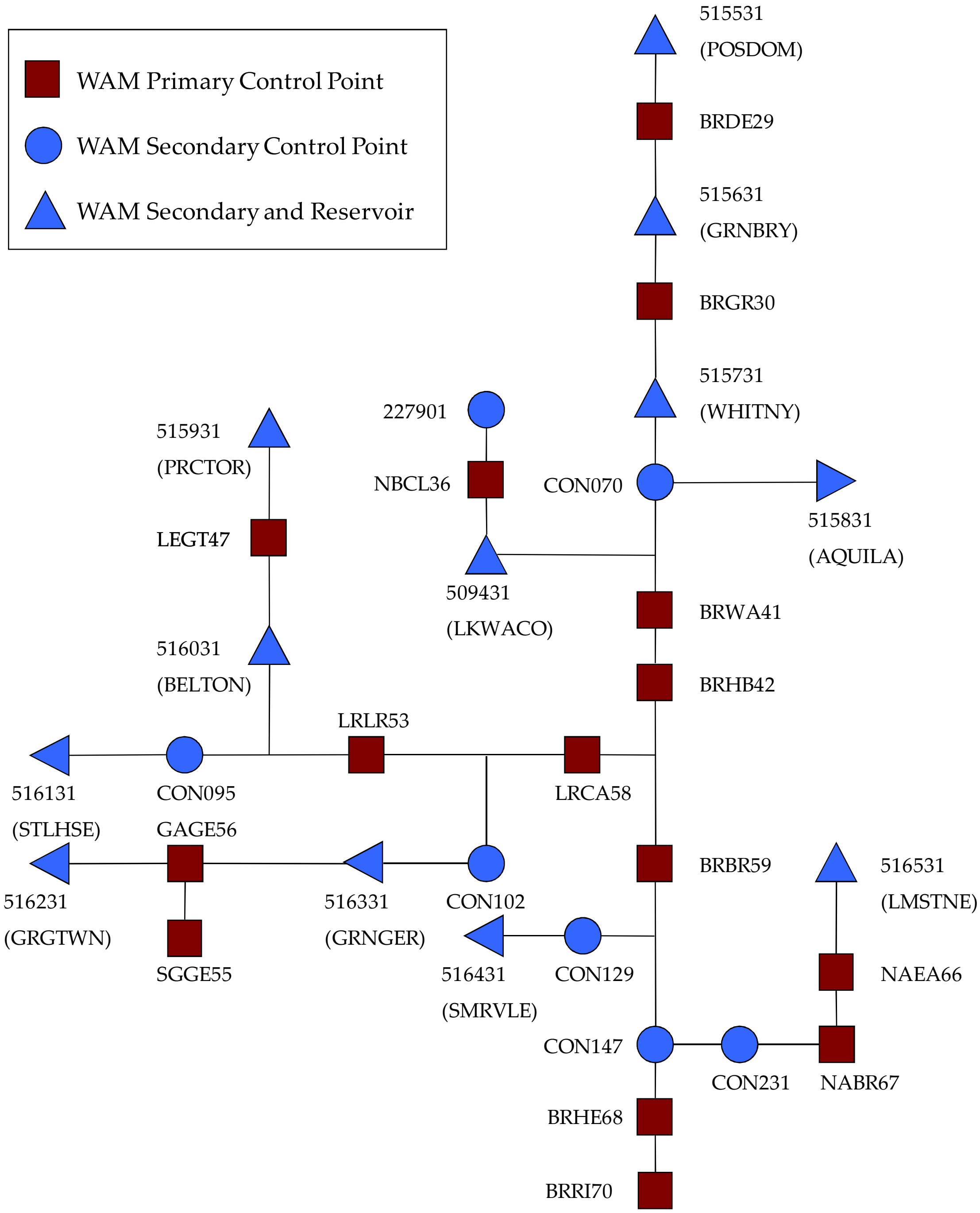

Figure 3.3 Connectivity of WAM Control Points Corresponding to Locations of SUPER Flow Data

Tables 3.3 and 3.4 show a comparison between the WAM monthly naturalized flow time series and the SUPER flows aggregated from daily to monthly volumes. Table 3.3 compares the WAM monthly naturalized flow and SUPER aggregated monthly unregulated flow at WAM ungaged control points. Table 3.4 makes the same comparison but at the locations of WAM primary control points. Differences in flow are computed for the mean, standard deviation, and maximum and at various values of flow exceedance.

Differences in flow tend to be a larger percentage of the WAM naturalized monthly flow during low flow conditions. The WAM naturalization process and the SUPER process for computing unregulated flows may result in different flows, especially if minor diversions and return flows were not adjusted in the SUPER flow dataset. Regardless, the WAM monthly naturalized flow volume will be preserved in SIMD during the process of disaggregation into daily flow sequences. Only the daily pattern of flow is set by the SUPER flow data.

Percent differences in high flows are generally smaller than the percent differences at low flows in Tables 3.3 and 3.4. The WAM naturalized flow dataset contains adjustments to peak flows that occur at the end and beginning of months. Since the monthly WAM simulation does not contain routing, some large storm flow events may have been moved between months so that the entire event fits into the same month for the entire basin. These WAM timing adjustments to storm flows in the naturalized flow data were not reversed prior to conducting the Bwam simulations for the case study.

Table 3.3 WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows at WAM Ungaged Control Points, ac-ft per Month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
516231	WAM	4,797	8,418	0	0	85	344	1,416	5,510	14,484	74,909
	SUPER	5,274	9,072	0	0	123	406	1,555	5,990	15,411	72,646
	Difference	-477	-654	0	0	-38	-62	-139	-480	-927	2,263
515831	WAM	6,147	11,987	0	0	0	37	988	6,582	19,446	102,561
	SUPER	7,185	13,855	0	0	20	234	1,344	7,344	21,786	124,101
	Difference	-1,038	-1,868	0	0	-20	-197	-356	-762	-2,340	-21,540
227901	WAM	9,653	21,769	0	0	121	538	1,870	8,331	28,445	302,330
	SUPER	9,949	22,708	0	0	134	620	1,929	8,564	29,668	329,012
	Difference	-296	-939	0	0	-14	-82	-59	-233	-1,223	-26,682
515931	WAM	12,071	28,547	0	0	56	495	2,450	10,841	33,218	327,284
	SUPER	11,494	27,093	0	0	87	652	2,300	10,189	31,331	326,715
	Difference	576	1,454	0	0	-31	-157	150	652	1,887	569
516331	WAM	15,552	24,898	0	6	474	1,773	5,412	19,756	44,908	210,085
	SUPER	16,258	25,212	0	119	740	2,207	5,841	19,985	45,384	208,010
	Difference	-706	-314	0	-113	-266	-434	-429	-229	-476	2,075
516431	WAM	18,572	33,188	0	0	5	764	3,895	18,888	60,673	250,982
	SUPER	20,245	34,435	0	0	190	1,525	5,204	22,125	63,996	248,272
	Difference	-1,672	-1,247	0	0	-185	-761	-1,309	-3,237	-3,323	2,710
516131	WAM	19,238	34,306	28	148	719	2,122	5,988	20,984	53,075	309,090
	SUPER	18,567	33,557	0	49	678	2,009	5,527	20,705	52,037	310,738
	Difference	671	749	28	99	40	113	461	279	1,038	-1,648
516531	WAM	19,399	34,018	0	0	101	614	3,970	21,035	62,911	240,424
	SUPER	20,448	34,643	0	3	176	837	5,281	21,740	66,553	240,850
	Difference	-1,048	-625	0	-3	-75	-223	-1,311	-705	-3,642	-426
CON095	WAM	24,263	41,021	0	430	1,445	3,363	8,124	27,288	66,398	351,724
	SUPER	24,099	39,495	0	391	1,664	3,544	9,193	27,413	68,566	350,683
	Difference	164	1,526	0	39	-219	-181	-1,069	-125	-2,168	1,041
CON129	WAM	25,966	43,479	0	0	619	2,066	7,069	27,509	84,897	322,760
	SUPER	31,286	46,377	0	341	1,229	3,786	11,137	37,245	102,195	358,204
	Difference	-5,320	-2,898	0	-341	-610	-1,720	-4,068	-9,736	-17,298	-35,444

Table 3.3 Continued

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
509431	WAM	29,789	53,352	0	9	468	2,860	9,933	34,692	80,535	530,557
	SUPER	28,906	53,160	0	91	915	2,842	9,542	30,462	79,278	499,977
	Difference	883	192	0	-81	-447	18	391	4,230	1,257	30,580
CON102	WAM	30,113	47,637	0	0	712	3,143	11,462	37,003	82,590	385,711
	SUPER	30,047	47,547	0	153	1,161	3,526	10,242	35,400	82,697	360,454
	Difference	67	90	0	-153	-449	-383	1,220	1,603	-107	25,257
516031	WAM	41,916	75,191	0	0	486	3,336	12,710	47,382	112,448	627,569
	SUPER	45,630	79,832	0	54	1,706	4,897	16,191	49,194	118,788	638,998
	Difference	-3,715	-4,641	0	-54	-1,221	-1,561	-3,481	-1,812	-6,340	-11,429
CON231	WAM	64,512	88,128	0	0	3,753	8,560	25,420	82,017	187,854	624,252
	SUPER	60,855	85,095	41	543	2,785	8,120	24,408	78,602	182,699	685,211
	Difference	3,657	3,033	-41	-543	969	440	1,012	3,415	5,155	-60,959
515531	WAM	66,123	137,150	0	0	2,187	6,883	18,404	64,389	166,332	1,794,484
	SUPER	66,259	134,668	0	830	4,052	8,598	20,808	63,683	166,345	1,806,223
	Difference	-136	2,482	0	-830	-1,865	-1,715	-2,404	706	-13	-11,739
515631	WAM	91,156	178,785	0	782	4,459	10,228	29,493	95,565	237,433	2,653,863
	SUPER	93,144	182,692	0	1,844	6,695	11,902	31,148	94,187	239,468	2,792,087
	Difference	-1,988	-3,907	0	-1,062	-2,236	-1,674	-1,655	1,378	-2,035	-138,224
515731	WAM	113,906	203,559	8	1,767	6,778	16,135	46,037	130,424	277,592	2,962,997
	SUPER	116,093	208,401	297	2,804	9,789	18,739	45,363	125,234	287,669	3,006,321
	Difference	-2,187	-4,842	-290	-1,037	-3,012	-2,605	674	5,190	-10,077	-43,324
CON070	WAM	130,089	222,662	0	2,454	7,920	20,524	56,178	144,695	342,884	3,096,309
	SUPER	132,601	225,994	585	3,186	11,371	22,899	57,929	149,793	342,029	3,124,326
	Difference	-2,512	-3,332	-585	-732	-3,451	-2,375	-1,751	-5,098	855	-28,017
CON147	WAM	434,029	579,775	1,424	16,028	42,367	85,443	223,684	566,908	1,126,324	5,562,412
	SUPER	385,886	537,742	4,083	15,249	38,061	75,026	186,755	472,948	951,539	5,418,890
	Difference	48,143	42,033	-2,659	780	4,306	10,417	36,929	93,960	174,785	143,522

Table 3.4 WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows at WAM Primary Control Points, ac-ft per Month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
SGGE55	WAM	3,014	5,397	0	11	60	241	946	3,497	8,301	50,622
	SUPER	2,977	5,325	0	3	61	239	938	3,496	8,241	50,622
	Difference	38	72	0	8	-1	2	8	1	60	0
GAGE56	WAM	8,693	15,106	0	27	204	751	2,754	10,232	25,510	140,494
	SUPER	8,251	14,236	0	11	218	658	2,532	9,461	25,422	123,179
	Difference	443	870	0	16	-15	93	222	771	88	17,315
NBCL36	WAM	13,577	31,085	0	0	166	771	2,594	11,722	40,586	450,470
	SUPER	13,629	31,060	0	0	183	840	2,647	11,847	40,559	449,932
	Difference	-52	25	0	0	-17	-69	-53	-125	27	538
LEGT47	WAM	21,483	41,916	0	0	383	1,361	5,793	21,255	56,294	383,340
	SUPER	23,652	47,879	0	0	401	1,392	5,898	23,656	59,491	430,910
	Difference	-2,169	-5,963	0	0	-18	-31	-105	-2,401	-3,197	-47,570
NAEA66	WAM	26,882	46,900	0	0	125	848	5,743	28,826	87,562	332,958
	SUPER	27,735	46,688	0	37	279	1,410	6,912	29,619	89,413	326,639
	Difference	-854	212	0	-37	-154	-562	-1,169	-793	-1,851	6,319
NABR67	WAM	35,109	57,655	0	0	295	1,759	8,530	40,035	109,997	384,272
	SUPER	38,486	58,709	0	98	810	3,127	10,764	47,633	125,002	379,429
	Difference	-3,378	-1,054	0	-98	-515	-1,368	-2,234	-7,598	-15,005	4,843
LRLR53	WAM	70,546	120,022	30	562	3,418	8,225	25,741	80,406	190,524	950,933
	SUPER	75,044	121,634	15	677	4,759	10,778	29,744	89,071	196,687	995,412
	Difference	-4,498	-1,612	15	-115	-1,341	-2,553	-4,003	-8,665	-6,163	-44,479
BRDE29	WAM	83,646	165,799	0	529	3,713	9,442	27,265	87,622	211,034	2,450,046
	SUPER	83,787	168,037	33	1,960	5,809	11,004	27,736	79,860	211,820	2,528,313
	Difference	-142	-2,238	-33	-1,431	-2,095	-1,562	-471	7,762	-786	-78,267
BRGR30	WAM	93,248	182,476	0	528	4,598	10,445	30,585	96,926	242,476	2,710,228
	SUPER	94,663	184,820	0	1,958	6,782	12,299	31,856	96,854	243,134	2,833,811
	Difference	-1,415	-2,344	0	-1,430	-2,184	-1,854	-1,271	72	-658	-123,583
LRCA58	WAM	109,858	170,466	0	1,249	5,440	15,032	44,799	130,473	290,433	1,403,136
	SUPER	114,664	177,292	122	1,385	6,568	17,166	47,182	136,409	294,857	1,446,929
	Difference	-4,805	-6,826	-122	-136	-1,128	-2,134	-2,383	-5,936	-4,424	-43,793

Table 3.4 Continued

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
BRWA41	WAM	161,860	266,253	0	3,434	10,364	24,749	68,642	183,578	422,755	3,376,485
	SUPER	164,614	271,325	1,471	4,575	12,831	27,669	69,098	182,415	422,385	3,475,462
	Difference	-2,753	-5,072	-1,471	-1,142	-2,467	-2,920	-456	1,163	370	-98,977
BRHB42	WAM	194,262	300,104	1,251	6,378	14,726	31,658	89,483	232,892	488,252	3,599,269
	SUPER	192,089	298,898	1,890	5,943	17,370	33,843	86,146	220,430	471,991	3,659,795
	Difference	2,173	1,206	-639	435	-2,645	-2,185	3,337	12,462	16,261	-60,526
BRBR59	WAM	335,664	483,897	0	11,162	28,173	60,717	158,629	402,271	810,073	4,704,312
	SUPER	343,562	501,143	2,661	12,738	31,917	63,917	166,181	414,285	854,640	5,091,260
	Difference	-7,898	-17,246	-2,661	-1,576	-3,745	-3,200	-7,552	-12,014	-44,567	-386,948
BRHE68	WAM	446,579	588,542	1,634	17,422	44,643	89,698	229,331	581,968	1,153,505	5,723,482
	SUPER	445,071	602,300	5,498	18,236	45,310	90,235	218,495	567,780	1,113,301	6,237,132
	Difference	1,507	-13,758	-3,864	-814	-667	-537	10,836	14,188	40,204	-513,650
BRRI70	WAM	487,519	613,002	0	25,402	53,888	111,204	257,456	653,272	1,230,723	6,135,975
	SUPER	479,525	633,801	4,468	22,451	48,924	101,488	249,022	607,449	1,227,600	6,713,006
	Difference	7,994	-20,799	-4,468	2,950	4,964	9,716	8,434	45,823	3,123	-577,031

Figure 3.4 compares the WAM daily disaggregated naturalized flow and the SUPER daily unregulated flow for year 1952 daily flows at the WAM primary control point for the Brazos River near Bryan, BRBR59. The WAM naturalized daily flows shown are those flows generated by SIMD after the disaggregation process using the SUPER daily flows as a pattern. The SUPER daily unregulated flows are the raw pattern used in the disaggregation. The WAM daily naturalized flows have the pattern of the SUPER flows but preserve the WAM monthly naturalized flow. Figure 3.5 shows the lower portion of the 1952 hydrograph to illustrate the disaggregation at lower flow rates that include variable and uniform flow regimes during the year.

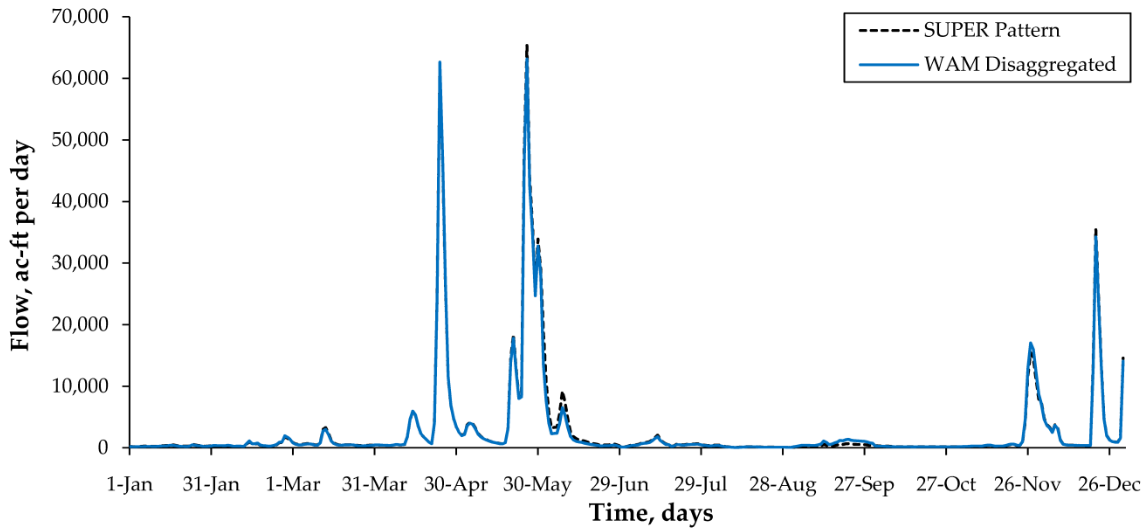

Figure 3.4 SUPER Flows and WAM Disaggregated Naturalized Flows at Bwam Control Point BRBR59 for 1952

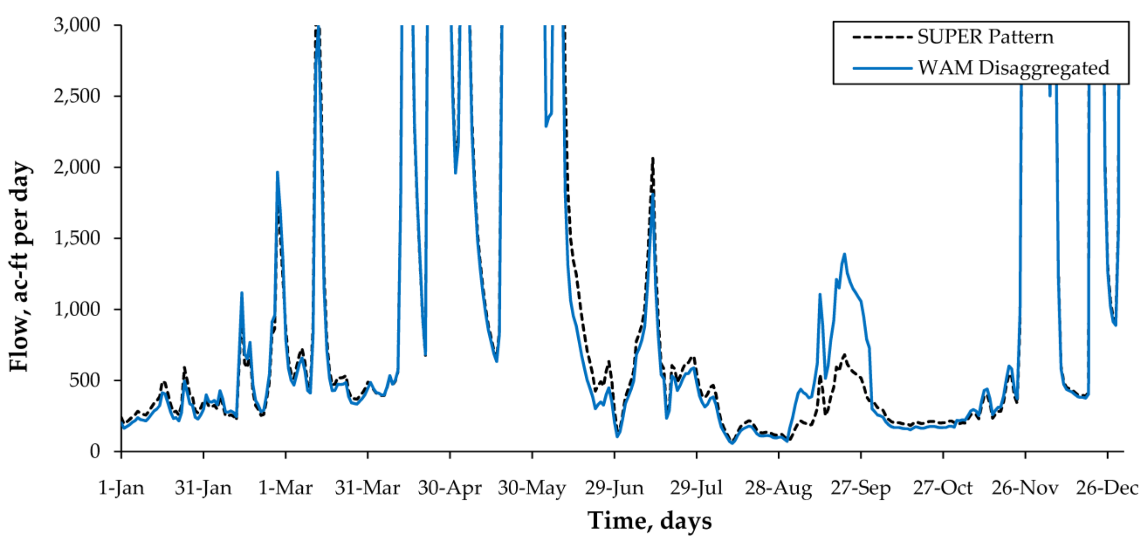

Figure 3.5 Lower Range of the SUPER Flows and WAM Disaggregated Naturalized Flows at Bwam Control Point BRBR59 for 1952

3.3 USACE Flood Control Operations

Damage reduction caused by extreme high flow events is the purpose of constructing and operating reservoirs with flood control storage (Wurbs and Carriere 1988). Nine major USACE reservoir flood control projects are located in the Brazos River Basin. Each flood control project consists of a flood control pool as a part of a multi-purpose reservoir. Conservation storage pools within a multi-purpose reservoir are managed by a local water supply sponsoring agency, such as the Brazos River Authority, for the purposes of water supply. Flood control operations for each multi-purpose reservoir are the responsibility of the federal government through the USACE.

3.3.1 Flood Control Storage Capacity

The nine USACE flood control reservoirs considered in the Bwam case study include Whitney, Waco, Aquilla, Proctor, Belton, Stillhouse, Georgetown, Granger, and Somerville. The elevation data for the top of the conservation pool, the top of the flood control pool, and the top of the dam are given in Table 3.5. The top of the conservation elevation data listed for Waco Lake is reflective of flood control storage reallocation for conservation storage purposes from 455 to 462 feet above mean sea level (ft msl). Reservoir storage reallocation from flood control to conservation is an increasingly common practice to meet water supply needs of areas with growing populations (Wurbs and Carriere 1988).

Table 3.5 Reservoir Elevation Data

Reservoir	Elevations, feet above mean sea level		
	Top of Conservation	Top of Flood Control	Top of Dam
Whitney	533.0	571.0	584.0
Waco	462.0	500.0	510.0
Aquilla	537.5	556.0	582.5
Proctor	1,162.0	1,197.0	1,205.0
Belton	594.0	631.0	662.0
Stillhouse	622.0	666.0	698.0
Georgetown	791.0	834.0	861.0
Granger	504.0	528.0	555.0
Somerville	238.0	258.0	280.0

Flood control storage capacity and surface area for the nine USACE flood control pools will be added to the storage volume and surface area (SV/SA) tables in the Bwam dataset. Addition of incremental gains in storage capacity and surface area to the Bwam SV/SA tables will be addressed in Chapter IV of this dissertation. The storage volume and surface area data for the flood control pools is adapted from *Evaluation of Storage Reallocation and Related Strategies for Optimizing Reservoir System Operations*, by Wurbs and Carriere (1988). The authors presented a series of reservoir storage reallocation simulations for the Brazos River Basin using the HEC-5 model. Flood control pool storage and surface area were presented in the report for estimated year 2010 sedimentation conditions for the nine USACE flood control reservoirs. The storage capacities for the estimated year 2010 sedimentation conditions are given in Table 3.6.

The Bwam Authorized Use dataset (Bwam3) simulates reservoirs according to their fully authorized conservation storage capacities. The incremental gains above the authorized conservation storage capacity due to inclusion of the flood control pool will be computed from the year 2010 sedimentation data. The common elevation demarking the top of conservation storage capacity in the fully authorized storage capacity and sedimentation adjusted storage capacity data will be used to compute incremental gains in storage capacity for the flood control pool. The extension of the Bwam3 SV/SA records is discussed in Chapter IV.

Table 3.6 Reservoir Storage Capacity Data, ac-ft

	Bwam Authorized	Estimated 2010 Sedimentation Conditions	
Reservoir	Conservation	Conservation	Flood Control
Whitney (inactive pool up to 520 ft msl)	249,076	227,950	1,364,250
Aquilla	52,400	47,340	91,720
Waco (conservation pool up to 462 ft msl)	206,562	157,790	506,410
Proctor	59,400	31,400	310,100
Belton	457,600	372,700	640,200
Stillhouse	235,700	209,700	391,220
Georgetown	37,100	34,540	91,900
Granger	65,500	57,070	173,720
Somerville	160,100	146,140	399,070

3.3.2 Flood Flow Limits

The USACE maintains documented operating schedules for each flood control reservoir. The flood control regulation schedules specify the reservoir releases that can be made under various conditions related to remaining reservoir storage capacity and downstream flow conditions. Regulation schedules are based on flood control conditions at specific reservoirs as well as consideration of system operations of multiple reservoirs to reduce flood damages across multiple locations within the basin.

The flood control reservoir operating schedules consist of two sets of procedures. Both procedures specify the largest rate of release from reservoir storage for the particular scenario of downstream flooding and remaining reservoir storage capacity. Assuming sufficient storage capacity remains in the reservoir to address the particular rate of flood inflow, a regular or standard flood control operating procedure is followed. If flood inflow conditions are predicted to result in storage contents exceeding the top of the dam, the alternate release operating procedure is implemented. The objective of flood control operation is to mitigate downstream damages due to reservoir releases as long as sufficient storage capacity remains available to retain flood inflows without exceeding the capacity of the flood control pool.

A summary of the USACE operating schedule for the nine flood control reservoirs in the Brazos River Basin can be found at http://www.swf-wc .usace.army.mil/pertdata/BRAZOS.htm. The information is a summary of maximum reservoir release rates and maximum allowable downstream flow rates with respect to reservoir storage content. The operating schedule is designed to retain storage within the reservoir, if storage capacity is available for the particular flooding conditions, to the extent that flow at the downstream gages does not exceed the maximum discharge rate as a result of reservoir releases. The information from the website is reproduced in Table 3.7.

The data from Table 3.7 will be used in Chapter IV to develop flood control input records for SIMD. The maximum flow limits at the Waco, Bryan, Richmond, Gatesville, Little River, and Cameron stream gages will be used to create targets for the SIMD FF records. FF records are utilized by upstream flood control reservoirs for testing whether to impound streamflow during the time step or allow releases from flood control up to the remaining available streamflow discharge capacity at the location of the FF records. Forecasting for regulated flow can be used in conjunction with FF records. The objective of regulated flow forecasting in SIMD is to constrain releases from flood control storage up to the limit of available streamflow discharge capacity at the location of the FF records over the forecast period. The data in Table 3.7 will also be utilized in Chapter IV to set maximum release volumes per time step for each flood control pool. The maximum release volume is provided on FR records.

Table 3.7 USACE Flood Control Discharges
(Elevations in msl, Flow Rate in cubic feet per second)

Reservoir	Elevations	% Flood Storage	Maximum Release	Brazos River	Aquilla Creek	Brazos River	Bosque River	Brazos River
				Turbine	Aquilla	Down to Bosque River	Near Gage	Waco
Whitney	533.0 - 533.5	0 - 1		2,200 Min.				60,000
	533.5 - 534.0	1 - 2		4,400 Min.				60,000
	534.0 - 571.0	2 - 100				25,000		60,000
Aquilla	537.5 - 538.0	0 - 2			3,000	25,000		60,000
	538.0 - 538.5	2 - 4			3,000	25,000		60,000
	538.5 - 539.0	4 - 5			3,000	25,000		60,000
	539.0 - 540.5	5 - 11			3,000	25,000		60,000
	540.5 - 556.0	11 - 100			3,000	25,000		60,000
	556.0 - 564.5	Surcharge			3,000	25,000		60,000
Waco	455.0 - 457.4	0 - 3					3,000	60,000
	457.4 - 460.0	3 - 7					5,000	60,000
	460.0 - 465.0	7 - 14					10,000	60,000
	465.0 - 470.0	14 - 23					20,000	60,000
	470.0 - 500.0	23 - 100					30,000	60,000

Table 3.7 Continued

Reservoir	Elevations	% Flood Storage	Maximum Release	Leon River	Leon River	Leon River	Little River	N. Fork San Gabriel River	San Gabriel River	Little River	Yegua Creek
				Proctor Near Gage	Hasse	Gatesville	Little River	Georgetown	Laneport	Cameron	
Proctor	1162.0 - 1168.0	0 - 10		500	2,000	5,000	3,000			10,000	
	1168.0 - 1197.0	10 - 100		2,000	2,000	5,000	6,000			10,000	
	1197.0 -			2,000	2,000	5,000	10,000			10,000	
Belton	594.0 - 596.5	0 - 5					3,000			10,000	
	596.5 - 610.0	5 - 35					6,000			10,000	
	610.0 - 631.0	35 - 100					10,000			10,000	
Stillhouse Hollow	622.0 - 625.0	0 - 5					3,000			10,000	
	625.0 - 640.0	5 - 34					6,000			10,000	
	640.0 - 666.0	34 - 100					10,000			10,000	
Georgetown	791.0 - 792.0	0 - 1	170					3,000		10,000	
	792.0 - 794.0	1 - 4	250					3,000		10,000	
	794.0 - 795.0	4 - 6	250					3,000		10,000	
	795.0 - 796.0	6 - 7	250					6,000		10,000	
	796.0 - 799.0	7 - 12	1,500					6,000		10,000	
	799.0 - 834.0	12 - 100	3,000					6,000		10,000	
Granger	504.0 - 505.0	0 - 2	150						6,000	10,000	
	505.0 - 506.0	2 - 5	300						6,000	10,000	
	506.0 - 507.0	5 - 8	650						6,000	10,000	
	507.0 - 518.0	8 - 47	3,000						6,000	10,000	
	518.0 - 528.0	47 - 100							6,000	10,000	
Somerville	238.0 - 243.0	0 - 18									1,000
	243.0 - 258.0	18 - 100									2,500

Table 3.7 Continued

Reservoir	Elevations	% Flood Storage	Brazos River	Brazos River	Brazos River
			Washington	Hempstead	Richmond
Whitney	533.0 - 533.5	0 - 1	60,000	60,000	60,000
	533.5 - 534.0	1 - 2	60,000	60,000	60,000
	534.0 - 571.0	2 - 100	60,000	60,000	60,000
Aquilla	537.5 - 538.0	0 - 2	60,000	60,000	60,000
	538.0 - 538.5	2 - 4	60,000	60,000	60,000
	538.5 - 539.0	4 - 5	60,000	60,000	60,000
	539.0 - 540.5	5 - 11	60,000	60,000	60,000
	540.5 - 556.0	11 - 100	60,000	60,000	60,000
	556.0 - 564.5	Surcharge	60,000	60,000	60,000
Waco	455.0 - 457.4	0 - 3	60,000	60,000	60,000
	457.4 - 460.0	3 - 7	60,000	60,000	60,000
	460.0 - 465.0	7 - 14	60,000	60,000	60,000
	465.0 - 470.0	14 - 23	60,000	60,000	60,000
	470.0 - 500.0	23 - 100	60,000	60,000	60,000
Proctor	1162.0 - 1168.0	0 - 10	60,000	60,000	60,000
	1168.0 - 1197.0	10 - 100	60,000	60,000	60,000
	1197.0 -		60,000	60,000	60,000
Belton	594.0 - 596.5	0 - 5	60,000	60,000	60,000
	596.5 - 610.0	5 - 35	60,000	60,000	60,000
	610.0 - 631.0	35 - 100	60,000	60,000	60,000
Stillhouse Hollow	622.0 - 625.0	0 - 5	60,000	60,000	60,000
	625.0 - 640.0	5 - 34	60,000	60,000	60,000
	640.0 - 666.0	34 - 100	60,000	60,000	60,000
Georgetown	791.0 - 792.0	0 - 1	60,000	60,000	60,000
	792.0 - 794.0	1 - 4	60,000	60,000	60,000
	794.0 - 795.0	4 - 6	60,000	60,000	60,000
	795.0 - 796.0	6 - 7	60,000	60,000	60,000
	796.0 - 799.0	7 - 12	60,000	60,000	60,000
	799.0 - 834.0	12 - 100	60,000	60,000	60,000
Granger	504.0 - 505.0	0 - 2	60,000	60,000	60,000
	505.0 - 506.0	2 - 5	60,000	60,000	60,000
	506.0 - 507.0	5 - 8	60,000	60,000	60,000
	507.0 - 518.0	8 - 47	60,000	60,000	60,000
	518.0 - 528.0	47 - 100	60,000	60,000	60,000
Somerville	238.0 - 243.0	0 - 18	60,000	60,000	60,000
	243.0 - 258.0	18 - 100	60,000	60,000	60,000

CHAPTER IV

METHODOLOGY FOR BUILDING CASE STUDY SCENARIOS

Chapter IV makes use of the daily unregulated streamflow data from the SUPER model and the USACE flood control reservoir capacity and flood control operating schedule presented in Chapter III. The data presented in Chapter III are used in this chapter for the following purposes:

- Organization of DF records from each source of SUPER daily unregulated flow for use by SIMD in the flow pattern method to disaggregate monthly Bwam naturalized flow sequences into daily naturalized flows.
- Calibration of routing parameters at each location of SUPER daily unregulated flow as input for the SIMD RT records.
- Development of FR records and FF records to realistically represent real-world USACE flood control reservoirs and flood control reservoir operating procedures.

Additionally, this chapter presents the alternative disaggregation methods used in the Bwam case study simulations. The alternative disaggregation methods are examined from the perspective of their effects on daily naturalized flow variability. The uniform and linear interpolation disaggregation methods do not utilize the SUPER daily unregulated flow sequences presented in Chapter III. Alternative forecasting periods, forecasting methods, and water right target distributions are presented. Alternative water right parameterizations, along with alternative disaggregation methods, form the basins for exploring the range of simulation outcomes in Chapters V and VI.

Two sets of key control points are referenced frequently throughout this research. The first set is used for examining flow frequency results for the water availability simulations. These control points are listed in Table 4.1 and shown in Figure 4.1 with the control point identifiers from the Bwam input files and the streams on which they are located. Table 4.1 and Figure 4.1 include five of the 77 primary control points and 12 secondary control points. The five primary control points include four United States Geological Survey (USGS) stream gaging stations and the outlet of the Brazos River at the Gulf of Mexico. The secondary control points are the sites of the 12 reservoirs managed by the BRA for conservation storage water supply. Nine of the 12 reservoirs are managed by the USACE for flood control. These nine flood control reservoirs are listed in Table 3.5.

The second set of key control points is used primarily for examination of simulation results for flood control operations. These 15 control points are listed in Table 4.2 and shown in Figure 4.2 with the control point identifiers from the Bwam input files and the streams on which they are located. The control points correspond to the location of the nine flood control reservoirs listed in Table 3.5 and the six streamflow gaging stations used for monitoring downstream flood flow conditions.

Table 4.1 Selected Control Points for Water Availability Simulation Analysis

Control Point ID	Reservoir or Gage	Stream	Drainage Area (square miles)
	USGS Stream Gaging Stations		
LRCA58	Cameron Gage	Little River	7,100
BRBR59	Bryan Gage	Brazos River	30,016
BRHE68	Hempstead Gage	Brazos River	34,374
BRRI70	Richmond Gage	Brazos River	35,454
	Outlet of the Brazos River at the Gulf of Mexico		
BRGM73	Gulf of Mexico	Brazos River	36,027
	Reservoirs		
515531	Possum Kingdom Lake	Brazos River	14,093
515631	Granbury Lake	Brazos River	16,181
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
516531	Limestone Lake	Navasota River	678
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases River	1,313
516231	Georgetown Lake	San Gabriel River	247
516331	Granger Lake	San Gabriel River	726
516431	Somerville Lake	Yegua Creek	1,008

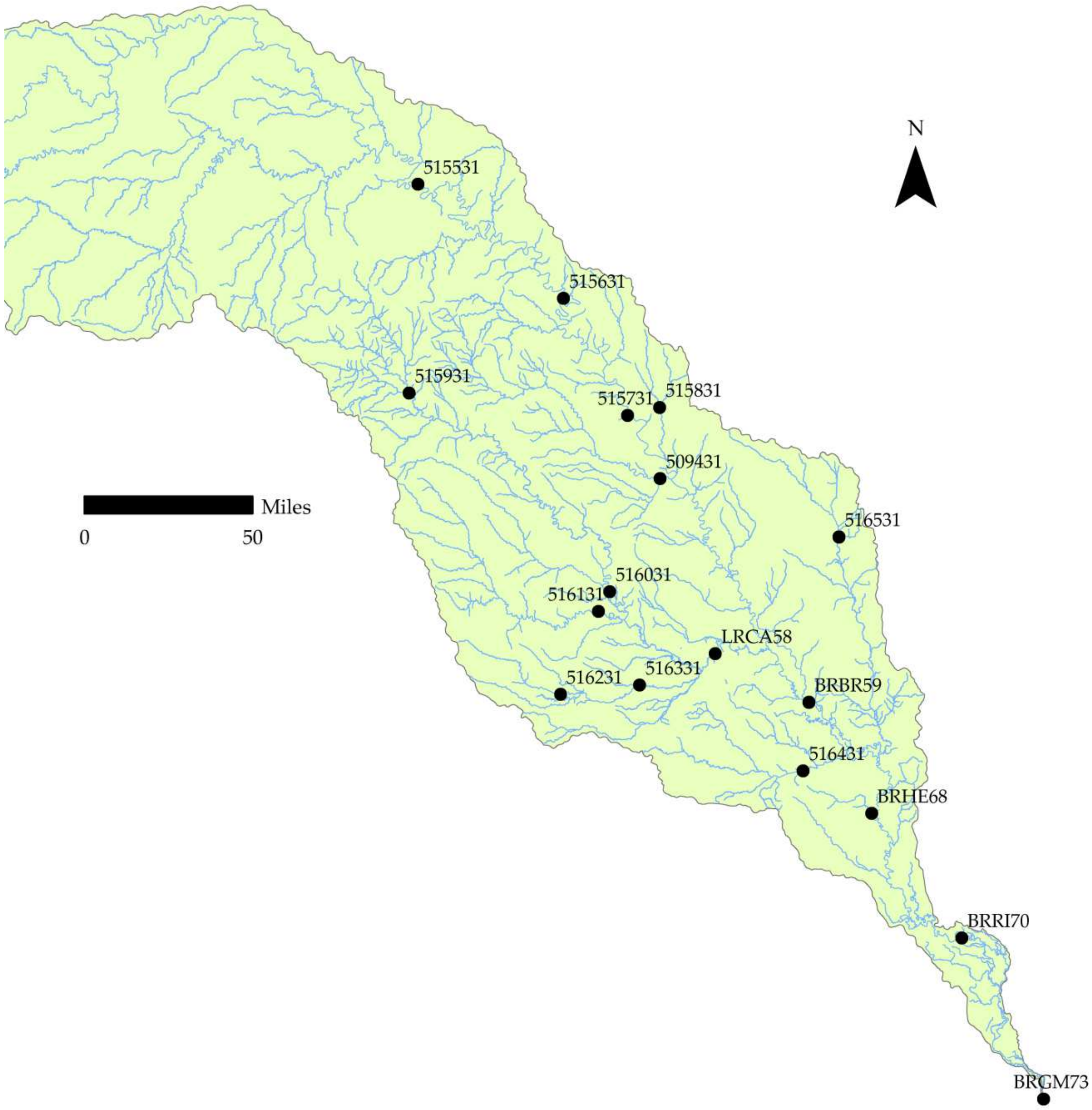

Figure 4.1 Selected Control Points for Water Availability Simulation Analysis

Table 4.2 Selected Control Points for Flood Control Simulation Analysis

Control Point ID	Reservoir or Gage	Stream	Drainage Area (square miles)
		USGS Stream Gaging Stations	
BRWA41	Waco Gage	Brazos River	20,065
BRBR59	Bryan Gage	Brazos River	30,016
BRRI70	Richmond Gage	Brazos River	35,454
LEGT47	Gatesville Gage	Leon River	2,379
LRLR53	Little River Gage	Little River	5,266
LRCA58	Cameron Gage	Little River	7,100
		Reservoirs	
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases River	1,313
516231	Georgetown Lake	San Gabriel River	247
516331	Granger Lake	San Gabriel River	726
516431	Somerville Lake	Yegua Creek	1,008

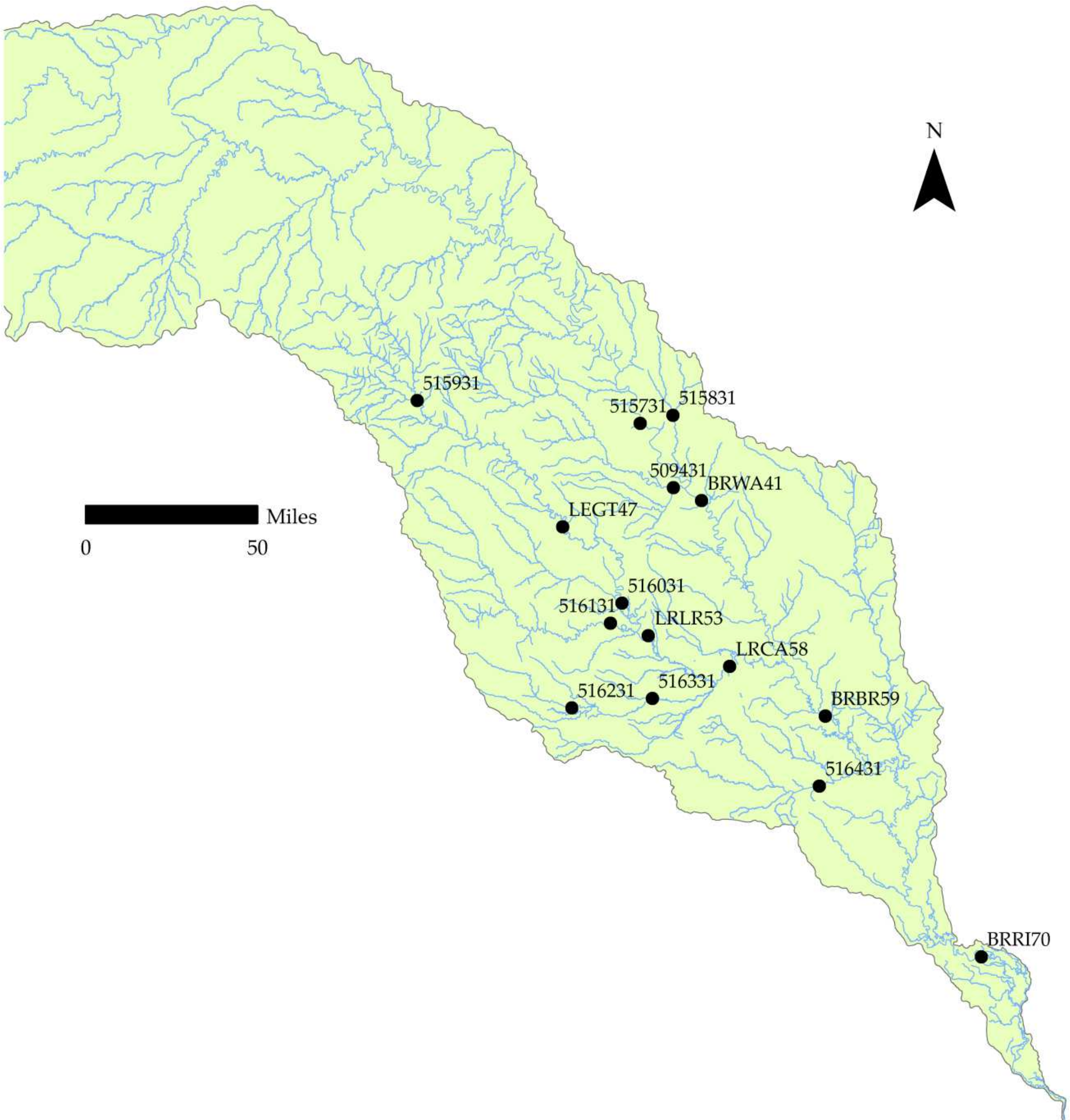

Figure 4.2 Selected Control Points for Flood Control Simulation Analysis

4.1 SIMD-specific Input Records

A primary input data file, DAT, for SIM and SIMD can be used interchangeably for monthly or daily simulations. All input records in the DAT file used by SIM for monthly simulation can also be read and used by SIMD for either monthly or daily simulation. To initiate a daily simulation, a JT record must be placed at the top of the DAT file after the monthly job control (JD) and simulation job options (JO) records.

The Bwam DAT is modified for the case study by adding the JT and JU records at the top of the DAT file. The JT record flags SIMD to initiate a daily Bwam simulation. Default JT record parameters are automatically adopted for any field of the record left blank. The JU record provides disaggregation options to be used if no monthly to daily control point disaggregation (DC) records are provided in the DCF file to override the JT record global value. The JT record also sets the method for placing changes to flow before the daily water rights loop. Table 4.3 shows an example of the JU and JT records used in the Bwam case study. Simulation results presented in Chapter V may utilize other values on the JT record to examine alternative parameterizations.

Table 4.3 Daily Job Control Records Used in the Bwam DAT File

```
**
JT      0    0    0      0    0      0    0    0    0    0
**
JU      1      0.0      0.0   0    1    1    0    0    0    0
**
```

The only additional SIMD records added to the Bwam DAT file pertain to resetting TO record target-building options from monthly to daily consideration. These WR/TO records are also paired with a DO record that sets a value of 13 in field 3. As discussed in the *Supplemental Manual*, this DO record setting causes TO record options to be considered in step 13 of the target-building process. There are no other SIMD records added to the Bwam DAT file to produce the results of Chapter V.

The SIMD-specific FR records and FF records are added to the Bwam DAT to facilitate the flood control simulations presented in Chapter VI. Flood control input record development is the subject matter of section 4.6 of this chapter.

The majority of SIMD-specific input records used for the Bwam case study are placed in the daily hydrology DCF file. The DCF file is populated with RT records, DC records, and DF records. Additionally, water right parameterization records can be placed in the DCF file. The DW records can be used to override any optional water right parameterizations set in the DAT file. DW records can be paired with selection criteria (SC) records. Adding pairs of DW/SC records to the DCF file allows water right parameters to be applied to any water rights fitting the selection criteria specified on the SC record. Pairs of DW/SC records are also added to the Bwam case study DCF file to specify forecasting periods and non-uniform target-setting parameters for certain groups of water rights. Discussion of forecasting period and water right target distribution parameters is contained in section 4.4 of this chapter.

4.2 Monthly to Daily Disaggregation

All control points in the Bwam are assigned monthly naturalized flows either through direct input by IN records in the FLO file or by transferring flows from gaged to ungaged control points. The drainage area ratio method with consideration of channel losses is used to transfer flows from gaged to ungaged control points in the Bwam DAT file. The monthly naturalized flows for every control point are disaggregated using the SUPER daily flows and thereby maintain the same monthly naturalized volume at every control point as utilized in the conventional monthly simulation.

The SUPER flows were provided by the USACE in units of average cubic feet per second per day. These values are not changed when the SUPER flows are formatted into DF records for the SIMD DCF file. The daily flow patterns on the DF records are not utilized as direct daily flow input. Instead, the DF record flows are utilized to compute sets of daily normalized coefficients in a process that is analogous to disaggregating WR record annual targets into monthly values using normalized coefficients computed from UC record values. Each set of daily normalized coefficients are computed from one monthly set of DF record values. The monthly naturalized flow at the control point is multiplied by the daily normalized coefficients to obtain the daily disaggregated naturalized flow. Therefore, units of the values of flow on the DF records do not affect the computation of the normalized coefficients used in this disaggregation method. However, if the user wishes to utilize DF record flows as direct daily streamflow input, a multiplier coefficient can be specified on the fourth field of the JU record. The multiplier can be used as a conversion factor from cubic feet per second to units of acre-feet per day.

4.2.1 Matching DF Record Patterns to Control Points

Each DF record is assigned the control point identifier of a Bwam control point that matches the location of SUPER flow data. Matches between Bwam control point identifiers and SUPER flow locations are given in Table 3.2. DC records are created for each Bwam DAT file control points to specify the disaggregation method at that control point. DC records are paired with a DF record set identifier. If the control point is coincident with the location of a DF record set, the DC record assigns the DF record set to that control point for the disaggregation. If any downstream DF record sets are available, then the DC record is assigned the first available downstream DF record set to the control point for disaggregation. If only upstream DF record sets are available, the DF record set is selected based on an evaluation of the DIS file drainage areas at the first encountered upstream DF record set locations. The DF record set is selected based on the minimum difference of drainage area between its location and the drainage area at the DC record location. If no DF record sets are located upstream or downstream of the DC record control point location, such as in the San Jacinto-Brazos Coastal Basin, the default JU record disaggregation method is assigned. Table 4.4 shows DC records for control points located coincident with the DF records at BRHB42 and BRBR59, DC records at locations paired to downstream DF records, and DC records at locations with neither upstream nor downstream DF record sets. Figure 4.3 shows a conceptual example of the DF record set assignment process.

Table 4.4 Example of DC Records for the Bwam Dataset

```
**
DC435901    4  BRHB42   1940    1    1997   12   0   0.000   0.000   0.000
DC435902    4  BRHB42   1940    1    1997   12   0   0.000   0.000   0.000
DCBRHB42    4  BRHB42   1940    1    1997   12   0   0.000   0.000   0.000
**
DCP41281    4  BRBR59   1940    1    1997   12   0   0.000   0.000   0.000
DC527101    4  BRBR59   1940    1    1997   12   0   0.000   0.000   0.000
DCBRBR59    4  BRBR59   1940    1    1997   12   0   0.000   0.000   0.000
**
DC557401    0              0    0       0    0   0   0.000   0.000   0.000
DCSJGBC3    0              0    0       0    0   0   0.000   0.000   0.000
**
```

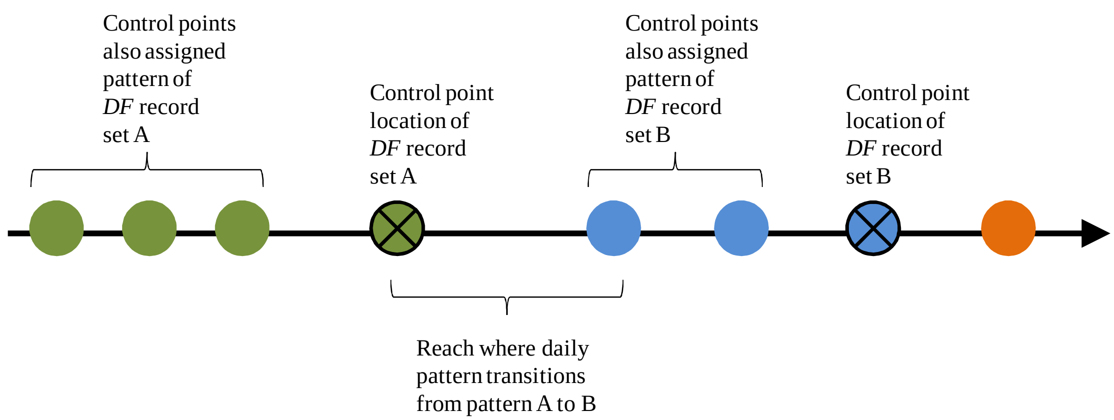

Figure 4.3 Example of Downstream DF Record Assignment

The SUPER flow data are used as a pattern source to disaggregate WAM monthly naturalized flow sequences into daily naturalized flows. No SUPER flow data are used in this case study for the San Jacinto-Brazos Coastal Basin. The uniform method of flow disaggregation is applied to develop daily flows for the control points in the coast basin in the Bwam dataset for the purposes of executing the Bwam simulation. Control point and water right output corresponding to the San Jacinto-Brazos Coastal Basin is not examined in Chapters V or VI.

4.2.2 Comparison of Disaggregated Daily Naturalized Flow

The flow-frequencies of daily naturalized flow at key streamflow gages and major reservoirs in the Bwam dataset are listed in Table 4.5. The table shows the daily naturalized flow frequency for the uniform, linear interpolation, and flow pattern disaggregation options at the control points listed in Table 4.1. The coefficients of variation for the three methods of daily naturalized flow disaggregation for each control point are given in Table 4.6. The coefficient of variation is a unitless normalized measure of dispersion computed as the standard deviation divided by the mean. A plot of the coefficient of variation for the three methods of daily naturalized flow disaggregation for each control point versus the control point drainage area is given in Figure 4.4.

Differences in flow frequency value are most evident in the low and high magnitude flows. In particular, locations with the highest daily flow coefficient of variation exhibit the greatest sensitivity to the disaggregation method. For example, the outlets of relatively small drainage basins like those for Lakes Aquilla and Limestone are located at control points 5151831 and 516531, respectively. The watershed area of Aquilla Lake is 254 square miles, and the watershed area of Limestone Lake is 678 square miles. Smaller drainage basins are expected to have flow characteristics more typical of direct runoff, whereas larger drainage basins may have a greater proportion of their time steps characterized by baseflow conditions. Since baseflow conditions tend to change less from day to day as compared to direct runoff conditions, the uniform and linear interpolation disaggregation methods may approximate the average daily flow condition in a larger number of time steps in the larger drainage basins where baseflow conditions may be more pronounced. However, day-to-day flow variability even during low baseflow conditions can still occur, which can cause the uniform and linear interpolation disaggregation methods to perform poorly for specific baseflow events. Direct runoff at locations far upstream can arrive at downstream locations in the form of a slow rise and fall of the daily hydrograph due to the effects of wave attenuation. The hydrographs of larger drainage basins are more likely to contain greatly attenuated direct runoff events that could be approximated by the uniform and linear interpolation methods. Like baseflow conditions, some attenuated direct runoff events may still contain enough day-to-day variability that only the use of flow patterns will provide realistic disaggregation results. Comparison of either the uniform or the linear disaggregation method to the flow pattern disaggregation method shows a dramatic difference in the flow frequency tables. In general, the flow-frequencies at all control point locations are sensitive to change from the uniform or linear interpolation method to the flow pattern disaggregation method.

Table 4.5 Flow Frequency of Daily Naturalized Streamflows for Three Methods of Disaggregation, acre-feet per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
					UNIFORM DISTRIBUTION						
LRCA58	3609.23	30971.6	0.00	36.58	84.37	178.53	485.00	1484.0	4319.3	9470.4	48384.0
BRBR59	11027.70	87717.8	0.00	360.19	592.80	911.03	1957.52	5295.3	13305.5	26782.3	151752.0
BRHE68	14671.64	106706.7	52.71	566.00	972.71	1464.74	2903.32	7615.1	19220.0	37804.3	184628.5
BRRI70	16016.66	111100.2	0.00	789.26	1282.57	1786.16	3675.33	8500.7	21358.3	39861.4	197934.7
BRGM73	16714.84	114966.0	0.13	827.47	1364.45	1918.39	3974.07	8999.7	22127.8	41621.7	201757.0
515531	2172.36	24761.9	0.00	0.00	8.00	68.27	223.70	608.5	2146.2	5404.2	57886.6
515631	2994.79	32270.9	0.00	23.41	66.12	148.95	330.84	969.0	3123.1	7723.2	85608.5
515731	3742.19	36763.3	0.25	48.93	108.57	220.13	528.09	1489.0	4223.7	9418.4	95580.5
515831	201.96	2173.3	0.00	0.00	0.00	0.00	1.07	32.1	209.6	623.0	3308.4
509431	978.66	9674.1	0.00	0.22	1.20	15.11	88.78	325.2	1120.7	2616.0	17114.8
516531	637.34	6168.5	0.00	0.00	0.99	3.20	19.85	128.6	691.4	1990.5	7755.6
515931	396.56	5179.9	0.00	0.00	0.01	1.78	16.21	79.0	348.8	1090.8	10909.5
516031	1377.07	13642.9	0.00	0.00	0.07	15.62	111.02	411.9	1533.5	3668.9	20244.2
516131	632.05	6231.6	0.90	4.70	16.08	23.81	68.98	194.4	686.0	1741.7	9970.7
516231	157.58	1533.9	0.00	0.00	0.61	2.69	11.09	45.8	177.8	469.4	2496.9
516331	510.93	4536.9	0.00	0.18	5.18	15.48	58.08	179.7	644.1	1488.6	7002.8
516431	610.17	6029.1	0.00	0.00	0.05	0.14	24.07	127.9	609.3	2021.8	8654.6
					LINEAR INTERPOLATION						
LRCA58	3609.23	33098.2	0.00	7.43	43.31	120.15	415.67	1329.2	4216.2	9779.3	71863.0
BRBR59	11027.70	93695.8	0.00	75.46	282.73	620.03	1656.13	4949.7	13291.5	28211.5	203605.2
BRHE68	14671.64	113466.7	0.29	175.37	521.84	1016.59	2521.61	6944.0	18766.1	37675.1	241718.9
BRRI70	16016.66	117537.1	0.00	284.08	770.09	1401.50	3216.28	7940.2	20527.8	40550.3	262967.8
BRGM73	16714.84	121654.7	0.01	319.90	808.90	1501.20	3497.15	8342.6	21573.2	42544.1	267816.1
515531	2172.36	26908.7	0.00	0.00	1.12	21.66	146.54	544.6	2097.8	5375.3	76829.3
515631	2994.79	34747.4	0.00	2.18	17.71	64.77	254.77	872.7	3095.6	7605.5	118275.1
515731	3742.19	39435.2	0.00	6.14	32.59	114.06	417.48	1319.8	4078.4	9631.6	130674.7
515831	201.96	2401.7	0.00	0.00	0.00	0.00	0.33	24.9	196.6	635.4	5996.3
509431	978.66	10414.5	0.00	0.09	0.70	4.87	62.10	274.5	1044.7	2660.5	27989.9
516531	637.34	6775.6	0.00	0.00	0.19	1.16	11.56	99.4	664.0	2051.3	13499.6
515931	396.56	5628.7	0.00	0.00	0.01	0.43	9.38	63.8	309.7	1053.1	17201.5
516031	1377.07	14590.9	0.00	0.00	0.05	4.24	83.41	379.6	1431.4	3791.2	30209.2
516131	632.05	6655.2	0.00	1.24	5.68	16.78	54.93	185.0	656.4	1740.7	16817.6
516231	157.58	1646.2	0.00	0.00	0.11	1.60	8.44	41.8	174.0	466.7	4467.0
516331	510.93	4859.3	0.00	0.08	2.23	9.32	46.47	170.2	614.9	1453.9	11700.6
516431	610.17	6604.3	0.00	0.00	0.03	0.13	13.85	104.6	601.5	1941.5	11630.1
					FLOW PATTERN						
LRCA58	3609.23	52884.7	0.00	15.60	40.40	86.35	309.13	941.4	3120.1	8211.2	289749.2
BRBR59	11027.70	136251.4	0.00	235.31	400.05	623.20	1309.30	3328.5	10061.4	26679.6	719015.3
BRHE68	14671.64	154395.5	4.72	407.49	640.35	988.37	2049.15	5018.9	15116.6	38178.6	759900.8
BRRI70	16016.66	157058.8	0.00	502.13	803.53	1199.23	2463.31	5975.9	17174.1	40730.7	645000.9
BRGM73	16714.84	161331.9	0.01	530.45	862.16	1286.37	2675.55	6389.1	17925.0	42078.3	586041.8
515531	2172.36	41586.8	0.00	0.00	0.00	0.00	62.92	365.6	1256.1	4078.0	192249.2
515631	2994.79	50689.1	0.00	1.20	33.00	77.03	233.16	614.3	1856.5	6112.8	178772.0
515731	3742.19	56352.8	0.00	16.16	62.19	124.25	340.67	904.9	2681.5	8381.6	193611.7
515831	201.96	6493.0	0.00	0.00	0.00	0.00	0.00	7.1	49.0	197.2	44240.4
509431	978.66	20698.6	0.00	0.00	0.48	3.59	34.17	168.4	630.5	1940.0	219455.4
516531	637.34	13890.4	0.00	0.00	0.00	0.00	5.30	36.8	211.3	1303.4	72246.6
515931	396.56	12970.0	0.00	0.00	0.00	0.00	2.55	28.8	138.7	685.9	200315.7
516031	1377.07	23458.8	0.00	0.00	0.00	0.76	43.41	250.3	1038.6	3157.8	165626.0
516131	632.05	13367.1	0.00	0.00	2.68	9.75	32.88	116.2	501.7	1461.6	120489.0
516231	157.58	3569.7	0.00	0.00	0.00	1.11	6.13	30.6	124.3	340.8	26837.0
516331	510.93	9253.5	0.00	0.00	1.34	6.76	33.23	114.8	433.6	1094.2	61175.3
516431	610.17	13080.9	0.00	0.00	0.00	0.00	4.20	45.5	265.6	1245.9	98735.3

Table 4.6 Coefficient of Variation for the Uniform, Linear Interpolation, and Flow Pattern Methods of Disaggregation

Control Point	Drainage Area, sq. miles	Method of Disaggregation: Uniform	Linear Interpolation	Flow Pattern
LRCA58	7,100	8.6	9.2	14.7
BRBR59	30,016	8.0	8.5	12.4
BRHE68	34,374	7.3	7.7	10.5
BRRI70	35,454	6.9	7.3	9.8
BRGM73	36,027	6.9	7.3	9.7
515531	14,093	11.4	12.4	19.1
515631	16,181	10.8	11.6	16.9
515731	17,690	9.8	10.5	15.1
515831	254	10.8	11.9	32.1
509431	1,655	9.9	10.6	21.1
516531	678	9.7	10.6	21.8
515931	1,280	13.1	14.2	32.7
516031	3,568	9.9	10.6	17.0
516131	1,313	9.9	10.5	21.1
516231	247	9.7	10.4	22.7
516331	726	8.9	9.5	18.1
516431	1,008	9.9	10.8	21.4

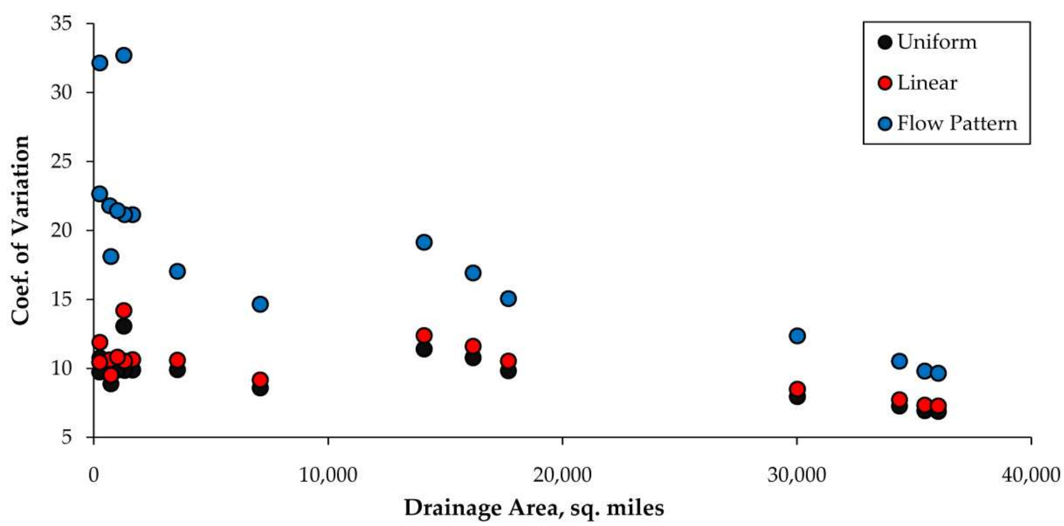

Figure 4.4 Coefficient of Variation versus Drainage Area

Figure 4.5 shows the flow exceedance curves at the location of Aquilla Lake for the uniform, linear interpolation, and flow pattern methods of disaggregating naturalized flow. All days in the Bwam period of record are represented in the figure. The flow exceedance curve for the flow pattern method of disaggregation crosses the uniform and linear interpolation method flow exceedance curves at 3.1% exceedance. Smoothing high flow events over multiple time steps in the uniform and linear interpolation methods of disaggregation creates flow exceedance values that are higher than those for the flow pattern method for all values of exceedance greater than 3.1%.

Figure 4.6 shows the flow exceedance curves at the location of the Richmond gage for the uniform, linear interpolation, and flow pattern methods of disaggregating naturalized flow. All days in the Bwam period of record are represented in the figure. The watershed area above the Richmond gage is 35,454 square miles. Unlike the relatively small drainage area upstream of the location of Aquilla Lake, the flow events at the Richmond gage may have a larger percentage of baseflow contribution and can be comprised of attenuated pulse flows from distant upstream tributaries. The flow exceedance curves at the Richmond gage are different for the three methods of disaggregation, though not as visually different as those presented in Figure 4.5 for the location of Aquilla Lake. The flow exceedance curve for the flow pattern method of disaggregation crosses the uniform and linear interpolation method flow exceedance curves for flows below 10.0% exceedance. The flow exceedance curve for the linear interpolation method crosses under the flow pattern curve at 90.1%.

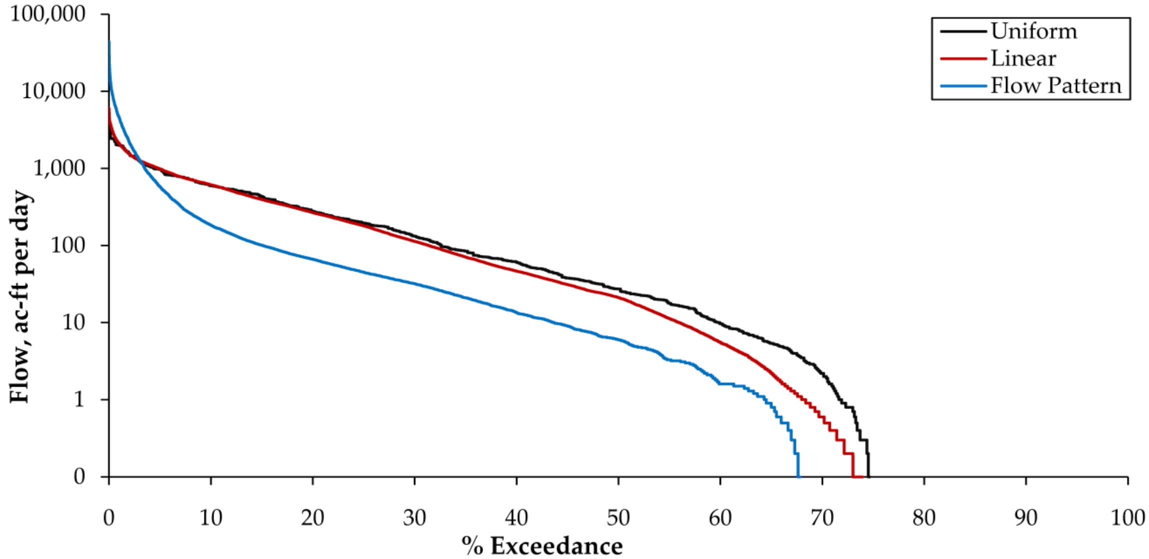

Figure 4.5 Flow Exceedance at Aquilla Lake

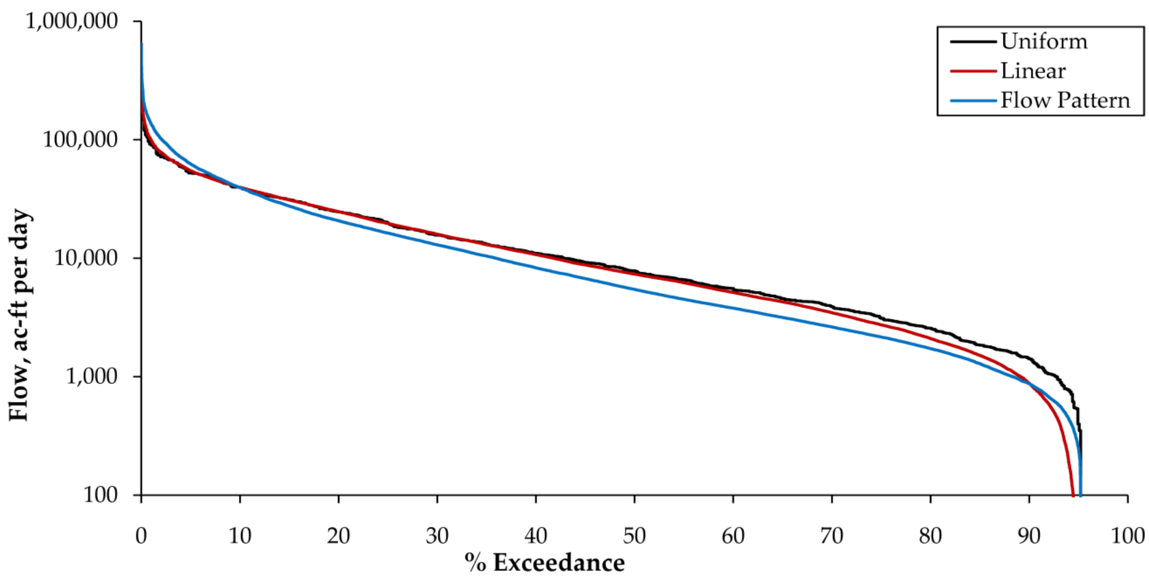

Figure 4.6 Flow Exceedance at the Richmond Gage

Figure 4.7 shows a portion of the Bwam period of record daily disaggregated naturalized flow at the location of Aquilla Lake. Figure 4.8 is the same sequence of flows at Aquilla Lake, but with a different scale on the ordinate axis to make the lower flow magnitudes visible. Figures 4.9 and 4.10 show the same period of flows, but at the Richmond gage. The daily naturalized flows at Aquilla Lake exhibit rapid rising and falling limbs of the hydrograph for the flow pattern disaggregation method. The uniform and linear interpolation disaggregation methods substantially smooth these peak events over the entire month. The daily flows for the three methods of disaggregation at the Richmond gage have similar relative performance, but with a larger proportion of the lower flows having influence from baseflow or distance upstream pulse flows. The linear interpolation flows in Figures 4.9 and 4.10 occasionally dip below the flows that are generated in the uniform and flow pattern methods of disaggregation. This is an artifact of the algorithm of fitting linear splines across months with large differences in total monthly flow volume.

In Figure 4.10, the uniform and linear interpolation methods of disaggregation match reasonably with the low flow period in January 1952 and September through October 1952. These periods were characterized by relatively uniform flows from day to day. Whenever the flow pattern is characterized by rapidly rising and falling flow rates, there is a larger divergence between the flow pattern method and the uniform and linear interpolation methods of disaggregation. The effect on water availability of the different methods of monthly to daily naturalized flow disaggregation is examined through the case study simulations in Chapter V.

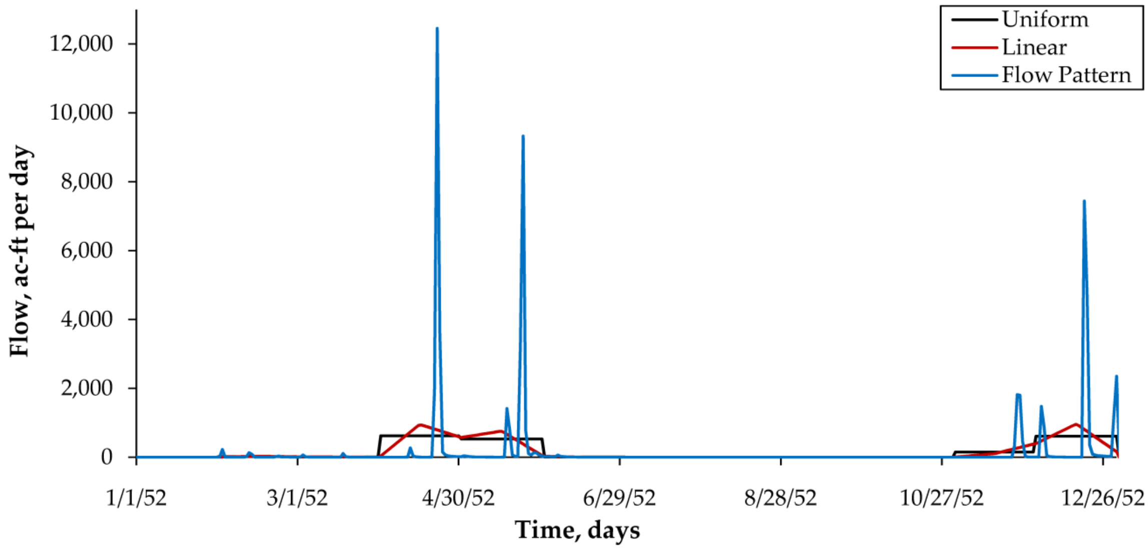

Figure 4.7 Daily Naturalized Flows at Aquilla Lake for 1952

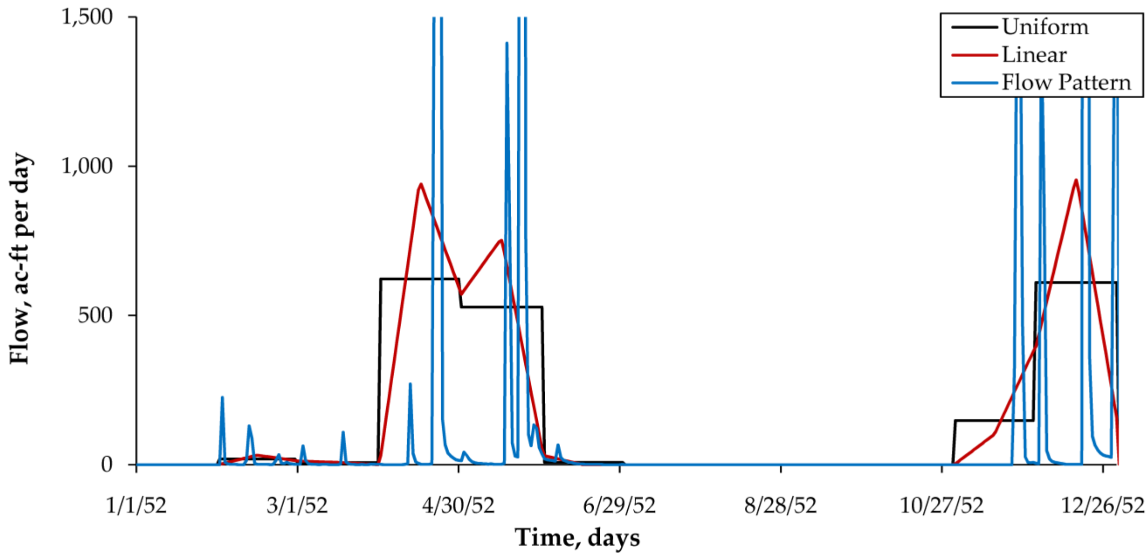

Figure 4.8 Lower Range of Daily Naturalized Flows at Aquilla Lake for 1952

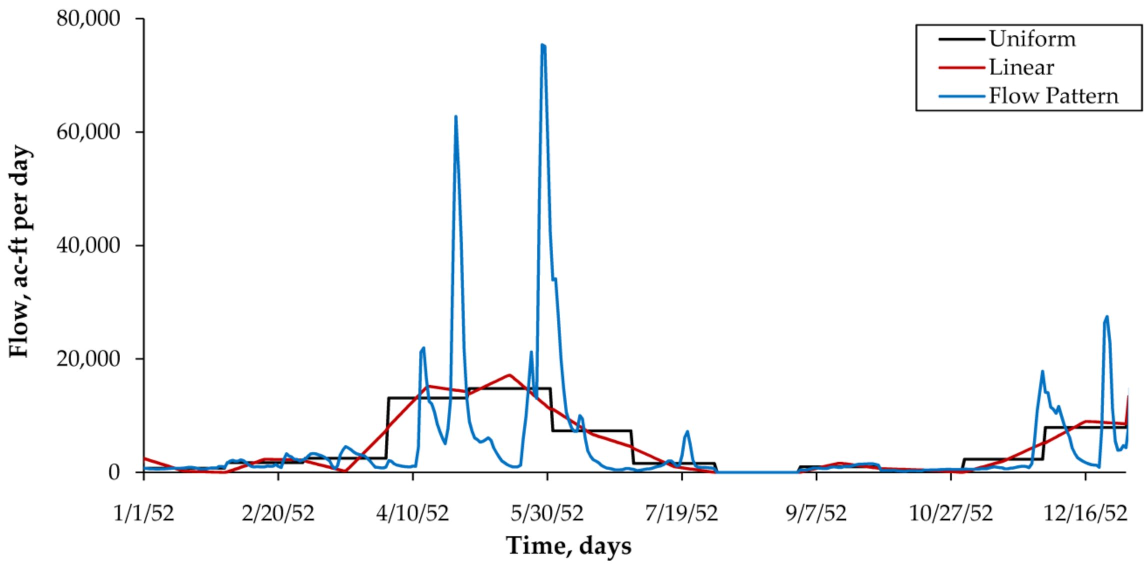

Figure 4.9 Daily Naturalized Flows at the Richmond Gage for 1952

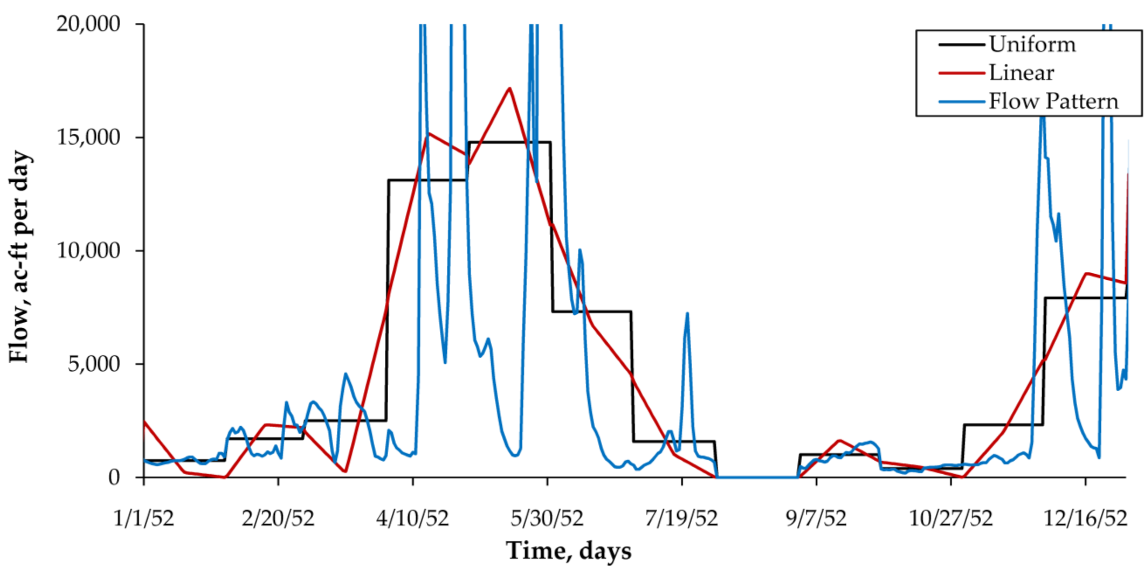

Figure 4.10 Lower Range of Daily Naturalized Flows at the Richmond Gage for 1952

4.3 Routing Parameter Calibration

This section describes the calibration of routing parameters for the Bwam period of record using the SUPER daily flow data. As discussed in section 4.2.1, the control points in the Bwam dataset are assigned the pattern of the first downstream SUPER daily flow pattern for disaggregation of monthly to daily flows. The SUPER flows are input as DF records in the DCF file. Assignments of the DF record daily patterns to each control point in the Bwam dataset are made on the DC records. Routing reaches are designated in the Bwam dataset at the same location of each DF record pattern set. The only exception is that no routing parameters are needed at the location of the most downstream DF record set. Designating routing reaches where the disaggregation transitions from one DF record flow pattern to the next ensures that travel time and attenuation between the flow patterns are also being applied to the changes in flow. An example of the transition of daily flow pattern is shown in Figure 4.3.

4.3.1 Calibration Settings in DAY

The program WRAP-DAY provides capability for calibrating routing coefficients over an unlimited period of record. Calibration of a single set of routing parameters represents the optimized set of parameters for minimizing differences between the observed downstream hydrograph and the hydrograph of the routed upstream flow sequences. Routing calibration can be performed simultaneously for any number of upstream gaged locations that have a common single downstream gaged outlet. DAY offers five objective functions to use in the calibration of routing parameters as discussed in section 2.4 of this dissertation.

Calibration of the Bwam routing parameters for all flow conditions utilizes objective function 5 with a weighting factor of 0.80. Objective function 5 is a linear combination of objective function 2 and objective function 3. Objective function 2 computes the mean absolute error between the routed and measured hydrographs. Objective function 3 computes the mean absolute error in daily lateral inflow volume. Therefore, parameters selected by DAY in the calibration routine provide an optimized minimum value that considers both the mean absolute error in lateral inflow volume and the mean absolute error. Objective function 3 is given a 0.80 weight and objective function 2 is given a weight of 0.20 in the calculation of objective function 5. Objective function 5 is utilized for calibrating routing parameters for all flow conditions because minimizing absolute errors in objective function 3 allows lower flow conditions nearer to the central tendency of the flow regime to contribute meaningfully to the objective function value.

Calibration of the Bwam routing parameters for high flow conditions utilizes objective function 4 with a weighting factor of 0.80. Objective function 4 is a linear combination of objective function 1 and objective function 3. Objective function 1 computes the mean squared error between the routed and measured hydrographs. Squared errors tend to favor the minimization of the objective function for peak flow events. Therefore, objective functions 1 and 4 are more suited for calibrating routing parameters to be used for high flow conditions. High flow conditions are defined as any time step in which the flow at the upstream end of the reach meets or exceeds the specified flow criteria. The calibration routine steps through every time step in the input dataset. However, only those time steps that meet the upstream flow threshold are used to compute the objective function value.

High flow conditions for the calibration are defined as any time step with a flow equal to or greater than the 25% exceedance level at the upstream end of the reach. The 25% exceedance level does not correspond to flow conditions that would typically warrant the use of flood control reservoirs to impound water. However, flood control releases in SIMD will be made after a flood event and will utilize the same routing parameters as used when the flood flows were impounded. The routing parameters should represent the range of high flow conditions under which both flood control storages and releases are made. Figure 4.11 shows the flow exceedance curve for the SUPER daily unregulated flows at the Bryan streamflow gage. The curve is developed with the Bwam DF record set for the 1940 to 1997 period of record. The 25% exceedance for the Brazos River near Bryan in the SUPER flow dataset is equal to 384,480 cubic feet per second (cfs).

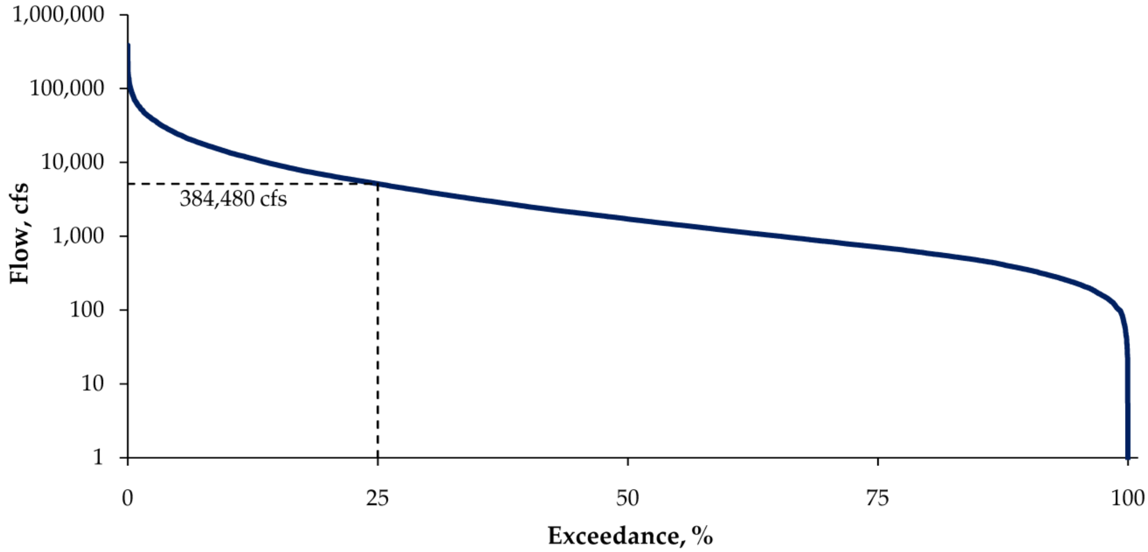

Figure 4.11 Flow Exceedance at Bryan Gage for SUPER Unregulated Daily Flows

4.3.2 Results of Calibration

Routing parameters are calibrated for each location of the SUPER flow data. The routing parameters are provided as input on RT records for the Bwam dataset. The calibration is performed between an upstream SUPER flow DF record set and the next downstream SUPER flow DF record set. All control points between DF record sets are assigned the pattern of the first downstream DF record set. There may be a short real-world spatial distance between a control point that is coincident with a DF record set and the next downstream control point that is assigned the DF records of the next downstream daily pattern. However, the routing parameters for the routing reach, as conceptually illustrated in Figure 4.3, are intended to simulate the travel time and attenuation effect occurring with the transition in patterns.

The lag and attenuation routing method is used for calibration of the Bwam routing parameters. Lag and attenuation is able to maintain the water balance for routing reaches with short travel time, unlike the Muskingum method. Some routing reaches in the Bwam dataset have much less than 1 day of travel time under certain flow conditions. These reaches may not be appropriate for calibration of Muskingum routing parameters.

DAY is used to calibrate the lag and attenuation routing parameters between each SUPER flow DF record set. The calibrated routing parameters are used as RT record inputs at the locations of the upstream DF record set. For example, in Figure 4.3 the calibration is performed with DF record set A and B. The routing parameters are used as RT record input for the control point location of DF record set A. The SIMD simulation routes flow from the location of DF record set A to the next downstream control point. No other routing parameters are encountered until the change in flow is passed to the control point location of DF record set B.

Where multiple upstream DF record sets have a common downstream DF record set, DAY can calibrate the routing parameters at each upstream location simultaneously for the outflow hydrograph at the common downstream location. For example, as shown in Figure 3.3, BRHB42 and LRCA58 have a common downstream SUPER flow DF record set at BRBR59. Calibrating the routing parameters in DAY simultaneously for BRHB42 and LRCA58 improves the mass balance with BRBR59 during the routing process more than if either BRHB42 or LRCA58 were calibrated separately.

Calibration of the lag and attenuation routing parameters is conducted for all flow conditions and for high flow conditions separately. The parameters calibrated for all flow conditions are used as input on the RT records for routing the changes to flow caused by WR record water rights. The high flow routing parameters are used as input on the RT records for routing the changes to flow caused by FR record flood control rights.

The results of the routing parameter calibrations are presented in Table 4.7 for all flow conditions and Table 4.8 for high flow conditions. All calibrations utilize the DF record sets developed from the SUPER flow dataset. The exception is the routing parameters in Table 4.7 for the Richmond control point. There are no SUPER flows below Richmond. In order to calibrate a set of routing parameters for the Richmond to Rosharon reach, USGS streamflow gaging data are utilized. Routing parameters for all flow conditions are calibrated for the Richmond reach as shown in Table 4.7. These lag and attenuation parameters are used in DAY to route the SUPER time series of flows at control point BRRI70. This produced a time series of flows for use at the Rosharon control point BRRO72 that are based entirely on the SUPER flows at Richmond but routed with the parameters in Table 4.7. High flow routing from Richmond to Rosharon in SIMD utilizes the same routing parameters.

The final two columns of Tables 4.7 and 4.8 are for comparing values of the routing parameters between control points. The singular value of lag and attenuation per control point in Table 4.7 are calibrated as the best fit for representing routing characteristics covering the entire range of flow conditions, all seasonal variations in streamflow, and all drought and flood conditions over a period of record with 21,185 daily time steps. Upstream control points contribute varying percentages of flow to their downstream outflow control point depending on the occurrence and timing of rainfall events in the adjacent contributing watersheds. Groundwater contributions to streamflow can vary by season or by the occurence of long-term drought conditions in particular watersheds or over particular regions. Information regarding river reach conditions such as gradient, channel geometry, and vegetation is not presented in the tables but is an important factor to consider when making relative comparisons of routing parameters between gaging locations. The value of lag and attenuation per control point in Table 4.8 cover a smaller and more consistent subset of flows. According to the lag and attenuation method of routing developed for SIMD, the lag parameter can be interpreted as the travel time for the last portion of the receding limb of a hydrograph to arrive at the downstream gage. Attenuation is the time over which the flow is distributed from the start of the rising limb to the end of the receding limb of the hydrograph. As seen in the last two columns of Tables 4.7 and 4.8, there is generally a low correlation between travel time and flow rate for reaches in the Brazos River Basin, both on an individual reach basis for different periods of time and on a reach comparative basis throughout the basin. A similar conclusion was reached by Mills (1970).

Table 4.7 Lag and Attenuation Routing Parameters for All Flow Conditions in the SUPER Period of Record—January 1940 to December 1997

River Reach						Calibration Results				Distance per Time	
Reach Name	WAM Inflow Control Pt.	WAM Outflow Control Pt.	Median Daily Inflow, cfs	Median Daily Outflow, cfs	Reach Length, miles	Lag, days	Att., days	Obj. Func. 5, cfs	Linear Corr. Coef.	Miles per Day of Lag	Miles per Day of Att
Possum Kingdom Outflow	515531	BRDE29	212	298	101	2.27	2.77	60	0.95	44.4	36.5
Dennis	BRDE29	515631	298	330	46	0.32	1.20	43	0.99	145.6	38.3
Grandbury Outflow	515631	BRGR30	330	349	32	0.64	1.27	5	1.00	50.3	25.2
Glen Rose	BRGR30	515731	349	467	65	0.62	1.25	75	0.94	104.5	52.2
Whitney Outflow	515731	CON070	467	565	28	0.36	1.23	31	1.00	78.4	22.7
Aquilla Outflow	515831	CON070	6	565	24	0.32	1.09	*	*	75.9	22.1
Bosque Outflow	227901	NBCL36	18	26	22	0.00	1.00	12	0.97	na	22.0
Clifton	NBCL36	509431	26	80	40	1.26	2.18	54	0.81	31.8	18.3
Lake Waco Outflow	509431	BRWA41	80	726	10	0.05	1.03	18	1.00	217.4	9.7
Elm Mott	CON070	BRWA41	565	726	16	0.44	1.09	*	*	36.7	14.7
Waco (Brazos)	BRWA41	BRHB42	726	889	60	1.23	1.85	100	0.98	49.0	32.4
Proctor Outflow	515931	LEGT47	15	55	120	3.71	3.39	40	0.85	32.3	35.5
Gatesville	LEGT47	516031	55	156	77	2.37	2.67	77	0.74	32.5	28.8
Stillhouse Outflow	516131	CON095	56	96	15	0.35	1.20	18	0.98	43.1	12.5
Lampasas Mouth	CON095	LRLR53	96	323	7	0.31	1.07	19	1.00	22.9	6.6
Belton Outflow	516031	LRLR53	156	323	23	0.54	1.41	*	*	42.8	16.3
Georgetown Outflow	516231	GAGE56	17	29	5	0.18	1.06	0	1.00	27.6	4.7
South Fork Outflow	SGGE55	GAGE56	11	29	3	0.19	1.10	*	*	16.1	2.7
Georgetown	GAGE56	516331	29	66	28	0.86	1.75	27	0.85	32.4	16.0
Granger Outflow	516331	CON102	66	109	26	0.62	1.41	46	0.93	41.8	18.4
Rockdale	CON102	LRCA58	109	504	16	0.00	1.00	43	0.99	na	16.0
Little River	LRLR53	LRCA58	323	504	62	1.53	1.78	*	*	40.5	34.8
Cameron	LRCA58	BRBR59	504	1,710	67	1.30	1.74	156	0.99	51.6	38.6
Highbank	BRHB42	BRBR59	889	1,710	68	1.25	1.36	*	*	54.5	50.1
Limestone Outflow	516531	NAEA66	22	48	17	2.30	2.86	24	0.97	7.4	6.0
Easterly	NAEA66	NABR67	48	93	34	3.28	3.42	36	0.97	10.4	9.9
Bryan (Navasota)	NABR67	CON231	93	235	60	6.23	4.11	75	0.92	9.6	14.6
Somerville Outflow	516431	CON129	32	97	14	0.19	1.12	37	0.96	73.7	12.5
Bryan (Brazos)	BRBR59	CON147	1,710	2,058	56	0.96	1.51	191	0.99	58.6	37.2
Yegua Mouth	CON129	CON147	97	2,058	23	0.02	1.00	*	*	1210.5	23.0
Navasota Mouth	CON231	CON147	235	2,058	6	0.01	1.00	*	*	666.7	6.0
Washington	CON147	BRHE68	2,058	2,490	32	1.30	2.18	281	0.97	24.6	14.7
Hempstead	BRHE68	BRRI70	2,490	2,860	105	1.49	1.67	188	0.99	70.7	62.9
Richmond**	BRRI70	BRRO72	3,490	3,490	38	0.91	1.70	166	0.99	41.8	54.3

* Values are given for the first reach listed in a multi-upstream inflow calibration.

** Gaged flow data used for USGS gages 08114000 and 08116650. Concurrent gaged flow period of record utilized was January 1968 through September 1980 and May 1984 through December 2008.

Table 4.8 Lag and Attenuation Routing Parameters for Flow Conditions Greater than or Equal to 25% Exceedance in the SUPER Period of Record—January 1940 to December 1997

River Reach						Calibration Results				Distance per Time	
Reach Name	WAM Inflow Control Pt.	WAM Outflow Control Pt.	25% Excdnc Inflow, cfs	Max Inflow, cfs	Reach Length, miles	Lag, days	Att., days	Obj. Func. 4, cfs	Linear Corr. Coef.	Miles per Day of Lag	Miles per Day of Att
Possum Kingdom Outflow	515531	BRDE29	661	90,596	101	1.73	2.70	739	0.94	58.3	37.4
Dennis	BRDE29	515631	834	95,785	46	0.08	1.04	306	0.99	582.3	44.4
Grandbury Outflow	515631	BRGR30	948	88,420	32	0.53	1.13	131	1.00	59.9	28.3
Glen Rose	BRGR30	515731	992	87,279	65	0.07	1.03	687	0.93	1000.0	63.0
Whitney Outflow	515731	CON070	1,360	112,782	28	0.23	1.21	378	0.99	123.3	23.2
Aquilla Outflow	515831	CON070	30	27,000	24	0.27	1.19	*	*	87.6	20.2
Bosque Outflow	227901	NBCL36	81	70,664	22	0.19	1.06	132	1.00	115.8	20.8
Clifton	NBCL36	509431	115	92,208	40	0.25	1.16	436	0.82	159.4	34.5
Lake Waco Outflow	509431	BRWA41	298	104,265	10	0.11	1.07	254	1.00	90.1	9.3
Elm Mott	CON070	BRWA41	1,618	146,190	16	0.37	1.10	*	*	43.6	14.5
Waco (Brazos)	BRWA41	BRHB42	2,118	227,752	60	0.84	1.33	676	0.95	71.4	45.3
Proctor Outflow	515931	LEGT47	69	100,817	120	3.08	3.38	359	0.84	39.0	35.5
Gatesville	LEGT47	516031	236	54,270	77	1.34	2.33	604	0.75	57.6	33.0
Stillhouse Outflow	516131	CON095	244	55,900	15	0.29	1.14	126	0.98	51.4	13.2
Lampasas Mouth	CON095	LRLR53	339	52,394	7	0.13	1.01	143	1.00	56.0	6.9
Belton Outflow	516031	LRLR53	579	91,637	23	0.58	1.33	*	*	39.7	17.4
Georgetown Outflow	516231	GAGE56	69	15,665	5	0.18	1.07	2	1.00	27.6	4.7
South Fork Outflow	SGGE55	GAGE56	40	8,435	3	0.17	1.01	*	*	17.4	3.0
Georgetown	GAGE56	516331	112	20,873	28	0.36	1.11	221	0.83	77.3	25.2
Granger Outflow	516331	CON102	229	31,151	26	0.48	1.30	392	0.92	53.8	20.0
Rockdale	CON102	LRCA58	364	46,975	16	0.00	1.00	418	0.99	na	16.0
Little River	LRLR53	LRCA58	1,074	110,331	62	1.11	1.22	*	*	55.7	50.7
Cameron	LRCA58	BRBR59	1,634	157,415	67	0.88	1.18	1,305	0.98	76.0	57.0
Highbank	BRHB42	BRBR59	2,593	228,919	68	0.99	1.21	*	*	68.5	56.2
Limestone Outflow	516531	NAEA66	122	36,489	17	1.43	2.18	227	0.97	11.9	7.8
Easterly	NAEA66	NABR67	198	43,584	34	2.37	2.46	246	0.95	14.3	13.8
Bryan (Navasota)	NABR67	CON231	406	37,356	60	4.45	3.78	570	0.81	13.5	15.9
Somerville Outflow	516431	CON129	164	49,900	14	0.14	1.11	202	0.96	100.7	12.6
Bryan (Brazos)	BRBR59	CON147	5,128	384,480	56	0.73	1.51	1,162	0.99	76.9	37.2
Yegua Mouth	CON129	CON147	364	46,972	23	0.00	1.00	*	*	na	23
Navasota Mouth	CON231	CON147	922	30,251	6	0.25	1.00	*	*	24.4	6.0
Washington	CON147	BRHE68	6,032	399,920	32	0.83	1.47	1,446	0.96	38.7	21.8
Hempstead	BRHE68	BRRI70	7,469	401,773	105	1.14	1.30	1,044	0.98	92.3	81.0

* Values are given for the first reach listed in a multi-upstream inflow calibration.

Tables 4.9 and 4.10 compare the calibrated lag and attenuation routing parameters for selected control points in Tables 4.7 and 4.8 to the calibrated values Muskingum *K* and *X*. Similar length reaches above the Hempstead reach but covering different regions of the basin were selected. Both routing methods give similar values of the objective function during the calibration process with DAY, though the Muskingum method tends to give slightly higher values on a consistent basis. Unlike the lag and attenuation method, which does not require a minimum distance between inflow and outflow control points, the Muskingum method does not maintain computational stability for values of *K* smaller than 0.50 days. Computationally unstable pairs of the Muskingum routing parameters *K* and *X* will occasionally produce negative streamflows at the outflow control point. Because some reaches listed in Tables 4.7 and 4.8 are short in distance and travel time, the Muskingum routing parameters cannot be fit to every routing reach listed in these tables. Muskingum routing is not utilized as a routing method in the Bwam case study.

Table 4.9 Lag and Attenuation and Muskingum Routing Parameters for All Flow Conditions in the SUPER Period of Record—January 1940 to December 1997

River Reach					Calibration Results			
Reach Name	WAM Inflow Control Pt.	WAM Outflow Control Pt.	Reach Length, miles	Routing Method	Lag or *K*	Att. or *X*	Obj. Func. 5, cfs	Linear Corr. Coef.
Glen Rose	BRGR30	515731	65	Lag-attenuation	0.62	1.25	75	0.94
				Muskingum	0.50	0.00	75	0.94
Waco (Brazos)	BRWA41	BRHB42	60	Lag-attenuation	1.23	1.85	100	0.98
				Muskingum	0.79	0.15	116	0.98
Gatesville	LEGT47	516031	77	Lag-attenuation	2.37	2.67	77	0.74
				Muskingum	1.69	0.26	80	0.81
Cameron	LRCA58	BRBR59	67	Lag-attenuation	1.30	1.74	156	0.99
				Muskingum	0.96	0.22	229	0.97
Highbank	BRHB42	BRBR59	68	Lag-attenuation	1.25	1.36	*	*
				Muskingum	1.11	0.36	*	*
Bryan (Navasota)	NABR67	CON231	60	Lag-attenuation	6.23	4.11	75	0.92
				Muskingum	4.92	0.10	101	0.84
Hempstead	BRHE68	BRRI70	105	Lag-attenuation	1.49	1.67	188	0.99
				Muskingum	1.21	0.37	294	0.97

* Values are given for the first reach listed in a multi-upstream inflow calibration.

Table 4.10 Lag and Attenuation and Muskingum Routing Parameters for Flow Conditions Greater than or Equal to 25% Exceedance in the SUPER Period of Record—January 1940 to December 1997

River Reach					Calibration Results			
Reach Name	WAM Inflow Control Pt.	WAM Outflow Control Pt.	Reach Length, miles	Routing Method	Lag or K	Att. or X	Obj. Func. 4, cfs	Linear Corr. Coef.
Glen Rose	BRGR30	515731	65	Lag-attenuation	0.07	1.03	687	0.93
				Muskingum	0.50	0.00	744	0.93
Waco (Brazos)	BRWA41	BRHB42	60	Lag-attenuation	0.84	1.33	676	0.95
				Muskingum	0.61	0.18	737	0.97
Gatesville	LEGT47	516031	77	Lag-attenuation	1.34	2.33	604	0.75
				Muskingum	1.31	0.08	619	0.75
Cameron	LRCA58	BRBR59	67	Lag-attenuation	0.88	1.18	1,305	0.98
				Muskingum	0.75	0.33	1,769	0.94
Highbank	BRHB42	BRBR59	68	Lag-attenuation	0.99	1.21	*	*
				Muskingum	0.81	0.34	*	*
Bryan (Navasota)	NABR67	CON231	60	Lag-attenuation	4.45	3.78	570	0.81
				Muskingum	2.47	0.20	643	0.57
Hempstead	BRHE68	BRRI70	105	Lag-attenuation	1.14	1.30	1,044	0.98
				Muskingum	0.98	0.45	1,640	0.93

* Values are given for the first reach listed in a multi-upstream inflow calibration.

4.4 Forecasting Periods

The Bwam dataset contains over 1,600 individual water right records. The number of permitted real-world water rights may differ. Included in these water rights are rights to impound and store water in reservoirs for later use. These water rights are spread over a large river basin and its tributaries and over a large range of priority dates. Some water rights have relatively few to no downstream senior water rights. In other cases, many water rights may be located over a network of tributaries with a common few downstream senior water rights.

Forecasting of future river flows may be considered from the dual perspectives of actual forecasts in the real world and computational forecasts in the SIMD model. Both are characterized by uncertainties and inaccuracies. The intent of forecasting for WR record rights in SIMD is the prevention of upstream junior rights from making depletions of streamflow in the current day that will otherwise be appropriated by downstream senior water rights during the forecast period. Selection of forecasting methods, FCMETH, and forecasting periods, F_P, should be done while considering the needs of downstream senior rights yet still allowing other water rights that are also upstream and junior to the same downstream senior rights to make depletions within the context of the doctrine of prior appropriation. Strict adherence to the doctrine of prior appropriation would require water rights to curtail their streamflow depletions in junior to senior priority order during times of shortage. However, dynamically individualizing a forecasting method and forecasting period for every possible combination of water right location, water right priority date, and tributary flow event during the period of record is not practical. SIMD allows only one forecasting period to be assigned to each water right. The forecasting period is used throughout the period of record. One approach taken with the Bwam dataset is to consider water right priority dates in the differential assignment of forecast periods.

The results of simulating the Bwam dataset with daily time steps are presented in Chapters V and VI. Chapter V deals with simulation results from the perspective of water availability. Chapter VI focuses on the addition of flood control operations to the simulation. In Chapter V, three cases of forecasting periods are presented. The three cases of forecasting periods are:

- no forecasting,
- a single global forecasting period of all WR record rights, and
- variable assignment of forecasting periods based on WR record priority.

Variable assignment of forecasting periods based on WR record right priority is handled with the use of DW/SC record pairs in the DCF file. For example, water rights with a priority date between January 1, 1930, and December 31, 1939, could be assigned a smaller value of F_P than those water rights with a priority date of January 1, 1940, and junior. The selection of different sets of water rights for assignment of the same F_P could be done based on any criteria available on the *SC* record. For the simulations presented in Chapter V, priority date by decade and type of use will be utilized as the selection criteria. The values of F_P assigned to WR record rights according to the SC record criteria are given in Table 4.11. In general, this will ensure that most junior water rights in the basin are simulated as curtailing their streamflow depletions first to meet downstream senior needs regardless of location or particular flow events. The last decade of priority dates selected are sub-divided so that non-municipal use water rights are given an extra day of forecasting over municipal use water rights with a similar priority date.

All water rights in the Bwam DAT file are assigned a forecasting period according to the criteria in Table 4.11 regardless of location. This includes water rights outside of the area covered by the SUPER flow dataset such as those water rights far upstream of Possum Kingdom Lake and in the San Jacinto-Brazos Coastal Basin.

Table 4.11 Assigned Values of Forecasting Period According to WR Record Priority Date and Type of Use

Criteria for Assignment of Forecasting Period	Forecasting Period, days
December 31, 1929, and Senior, all uses	0
January 1, 1930, to December 31, 1939, all uses	1
January 1, 1940, to December 31, 1949, all uses	1
January 1, 1950, to December 31, 1959, all uses	2
January 1, 1960, to December 31, 1969, all uses	2
January 1, 1970, to December 31, 1979, all uses	3
January 1, 1980, and Junior, municipal use	4
January 1, 1980, and Junior, non-municipal use	5

4.5 Water Right Target Demand Distribution

The monthly target is set at the beginning of the month as specified by a WR or IF record and accompanying UC, TO, SO, FS, DI, TS, and other optional auxiliary records. The monthly target is distributed over the days of the month based on either a uniform distribution or the features controlled by the number of days for target building, ND. When using a non-uniform target distribution as set by a positive value of ND, the option to recover shortages within the month is set by the parameter SHORT. The ND and SHORT parameters can be set globally on the JU record and can be overridden for individual water rights by options activated by the DW record associated with each individual water right. The selection of ND for Bwam water rights is intended to evaluate the relative effects on simulation results presented in Chapter V.

Without changing the JU or DW record defaults, all daily water use targets are built with a uniform monthly distribution. The monthly water use targets derived from the WR/IF and UC records are distributed evenly by the number of days in the month. This may be an appropriate assumption for water rights that require a constant daily target across all days of the month. Examples of such water rights can include municipalities with little meaningful storage capacity and instream flow requirements. The Bwam dataset, however, contains a large diversity of water right types as identified by their respective UC records. For example, many water rights in the Bwam dataset are identified as agricultural water users. Agricultural users may have on-farm storage capacity or may likely only require several days of pumping in any particular month of the growing season. Users who likely do not require simulation with water use targets every day of the month are modeled with positive values of ND and SHORT.

IF record rights in the Bwam dataset are not assigned a positive value of ND. In Chapter V, two cases of the application of ND are presented. The first case involves ND set to zero for all water rights. This results in uniform water use targets across all days of the month. The second case applies the values of ND shown in Table 4.12 according to the WR record rights' respective UC record use types.

Table 4.12 Assigned Values of Parameter ND According to Use Type

Use Category	ND Parameter, days
Municipal	28
Industrial	20
Hydropower	20
Mining	20
Agriculture (Irrigation)	14
Domestic & Livestock	14

4.6 Flood Control Operations

Adding SIMD-specific records to the simulation DAT file for flood control operations consists of providing, at a minimum, FR records. The FR records define the following characteristics of flood control reservoirs for the simulation:

- reservoir identifier;

- control point location;
- separate storage and release priority numbers;
- alternate water availability calculation for storage decisions;
- maximum daily release volume;
- storage capacity of a controlled flood control pool, Figure 2.4;
- storage capacity of an uncontrolled flood control pool, Figure 2.4;
- flood control system balancing coefficients;
- default storage volume versus surface area relationship; and
- multiple component reservoir evaporation allocation identifier.

Additional SIMD records are likely to be required, however, to properly model real-world flood control operations. In particular, downstream FF records are needed to define downstream locations for monitoring regulated flows. Upstream FR record reservoirs can utilize an unlimited number of downstream FF records for making storage and release decisions. The uncontrolled pools of the FR record reservoirs release water from storage based solely on volume versus discharge FV/FQ records. The following sections describe the additional SIMD-specific records that were constructed for use in the Chapter VI flood control simulations.

4.6.1 Flood Control Routing

Changes to flow are routed downstream in SIMD using the first set of routing parameters listed on the RT records in the DCF file. These routing parameters are applied to changes to flow made by WR or IF record rights. Changes to flow made by FR record flood control reservoirs can be routed using the same routing parameters as used by WR and IF record rights, or the second set of routing parameters on the RT record can be used exclusively for flood control routing. The lag and attenuation routing parameters presented in Table 4.10 are used to route flood control changes to flow for all simulations presented in this chapter. These routing parameters were calibrated for the high flow conditions that would be expected during flood control operations.

4.6.2 Flood Control Storage Capacity

Incremental pool storage capacities were taken from the model data presented by Wurbs and Carriere (1988) and adapted to FR records to define flood control capacity above conservation storage. The top of the conservation pool is equal to the authorized conservation storage capacity in the Bwam3 DAT file. This forms reservoirs in Bwam3 with authorized conservation storage capacities underneath flood control pools with storage capacities equal to year 2010 estimated sedimentation conditions. Uncontrolled flood control pools are added to the top of the controlled flood control pools on the FR records. The uncontrolled flood control pools are formed by the incremental volume above the top of flood control and up to the maximum design water surface.

Whitney and Waco Lakes are the only two flood control reservoirs modeled as separate reservoirs from their respective conservation pools. The Bwam conservation pools for Whitney and Waco Lakes are modeled as separate pools connected by evaporation-allocation (EA) records. The incremental flood control pools of Whitney and Waco Lakes are also connected to their respective separate conservation pools by the shared EA records.

4.6.3 Storage Volume versus Surface Area

Incremental pool surface areas versus incremental storage volumes were computed from the model data presented in Wurbs and Carriere (1988). The flood control portion of the incremental surface area versus storage volume data were added to the SV/SA records in the Bwam DAT file. The SV/SA relationship was extended beyond the top of flood control to account for the storage volume up to the maximum design water surface for the flood control reservoirs. The Bwam SV/SA records for Belton Lake are shown in Table 4.13. The SV and SA records are contiguous in the Bwam DAT file but are presented in Table 4.13 in separate rows to show where the incremental flood control data are added to the existing SV/SA records.

Table 4.13 SV/SA Records for Belton Lake, ac-ft vs. acres

SV/SA Record Data to the Top of Authorized Conservation

SVBELTON	0	40	160	650	1100	1800	20900	58700	123500	218100	304170	457600
SA		17	32	63	110	200	1760	3270	5290	7580	9261	12258

SV/SA Record Data above the Top of Authorized Conservation to the Top of Flood Control

SV	495550	535400	577400	636650	683800	768700	861400
SA	12903	13618	14293	15298	16128	17688	19428

SV/SA Record Data above the Top of Flood Control to the Maximum Design Water Surface

SV	1097800	1214900	1464900	1964900
SA	23618	23958	28758	37958

4.6.4 Storage Volume versus Discharge

Storage volume versus discharge data are provided for the flood control reservoirs on FV/FQ records. These records were developed from maximum conduit and spillway discharge capacity versus elevation data at each reservoir. The elevation data were mapped to the storage capacities developed for the FR records and SV/SA records. When flood control storage exceeds the top of flood control, the release from the uncontrolled pool is not governed by flood discharge limits at the dam or at downstream flood flow gaging stations. Instead, the daily discharge from the uncontrolled pool is computed only as a function of storage volume using the FV/FQ records. Discharge from the controlled flood control pool are computed as the minimum of the discharge according to the FV/FQ records or the stream capacity between regulated flows and maximum allowable flood flow limits at the dam or at downstream flood flow gaging stations. Table 4.14 shows the FV/FQ records for Belton Lake.

Table 4.14 FV/FQ Records for Belton Lake, ac-ft vs. ac-ft per Day

```
FV/FQ Records for Maximum Conduit Releases

FVBELTON    0   457600   495550   535400   577400   636650   683800   768700
FQ          0    46811    47604    48199    48992    49984    50579    51769

FV     861400     1097800   1214900   1464900   1964900
FQ      52959       55141     75175    291575    968940
```

4.6.5 Flood Control Reservoirs

The USACE flood control operating schedule for the Brazos River Basin is presented in Table 3.7. The information in Table 3.7 is adapted to SIMD FR and FF records. Portions of the total flood control storage capacity are represented in SIMD by multiple FR records per flood control reservoir. The multiple FR records per flood control reservoir are used to establish different values of maximum release according to the USACE operating schedule.

Lakes Whitney and Waco and Lakes Belton and Stillhouse Hollow are operated in SIMD as flood control storage and release systems. The storage priority dates and release priority dates on the FR records are set equal to each other. This establishes a system for either storing or releasing from the controlled flood control pool for that portion of the controlled flood control capacity defined on the respective FR record. Multiple FR records are used to establish different values of the maximum controlled pool release volume per time step (FCMAX). Additionally, multiple FR records are used for Whitney, Waco, Belton, and Stillhouse Hollow to facilitate balancing flood control storage contents as a percentage of total flood control capacity. As the Whitney-Waco or the Belton-Stillhouse systems impound or release flood water, each reservoir pool in the system will function as a zone to be considered before impounding or releasing from the next priority zone in the system. Multiple system pairings via equal priority numbers on FR records increase the likelihood of balancing flood control storage contents across the system pools.

The FR records for the nine flood control reservoirs are shown in the table on page 121. The conservation pools for Whitney and Waco Lakes are broken into multiple separate WS record reservoirs in the Bwam DAT file. The flood control reservoirs for Whitney and Waco Lakes are also modeled as separate reservoirs. Therefore, the FR record value for the bottom of flood control for the Whitney and Waco flood control reservoirs is equal to zero storage capacity. All other flood control reservoirs have a value for the bottom of flood control capacity that is equal to the top of the conservation pool capacity.

The priority numbers on the FR records were chosen to be the most junior rights in the Bwam DAT file. WR record rights in the DAT file with priority numbers equal to 99999999 were renumbered to 88888888. Flood control storage rights are assigned priority numbers equal to 91000000 through 91000071. Flood control release rights are assigned priority numbers equal to 92000900 through 92000990. The priority numbers were chosen to establish a relative storage and release order and to create storage and release systems. SIMD allows any priority numbering scheme as long as increases in storage capacity are assigned a junior priority to previously established storage capacities. Flood control storage decisions are prioritized in the following order: Whitney-Waco system, Aquilla, Proctor, Georgetown, Granger, Belton-Stillhouse Hollow system, Somerville. The storage priorities are arranged to generally follow an upstream to downstream order of storage decisions. Flood control release decisions are prioritized in the following order: Proctor, Georgetown, Somerville, Belton-Stillhouse Hollow system, Granger, Aquilla, Whitney-Waco system. The release priorities are arranged to generally follow a downstream to upstream order of storage decisions with the exception of Proctor and Georgetown. These reservoirs make release decisions first because they are located upstream of other flood control reservoirs. Belton should consider Proctor's releases and

Granger should consider Georgetown's releases prior to making additional flood control releases.

The FR record flood control reservoirs deplete all flow at their respective control points when regulated flows exceed the value of FCMAX at the location of the reservoir or when regulated flows exceed the target set by any of the downstream FF record flood flow gages. The option to deplete all flow is set by FR record parameter FCDEP equal to 2. FCDEP equal to 1 will limit depletions for flood control according to the standard water availability calculation, which considers all downstream control points.

The maximum release rate, FCMAX, for Proctor is listed as 7,934 ac-ft per day, or 4,000 cfs, in Table 4.15. This differs from the 2,000 cfs maximum rate shown in Table 3.7. The maximum discharge rate for Proctor was set to 7,934 ac-ft per day to reflect updated operational protocols for flood control releases from the lake.

Table 4.15 FR Record Representation of Flood Control Reservoirs

** RES	CPID STORE REL	FF	DEP	FCMAX	TOP	GATE	BOTTOM
FRWTNYFC	5157319100000092000990	0	2	49588	313780	313780	0
FRWTNYFC	5157319100000592000977	0	2	49588	545698		313780
FRWTNYFC	5157319100000692000976	0	2	49588	750335		545698
FRWTNYFC	5157319100000792000975	0	2	49588	954970		750335
FRWTNYFC	5157319100000892000974	0	2	49588	1091395		954970
FRWTNYFC	5157319100000992000973	0	2	49588	1159610		1091395
FRWTNYFC	5157319100001092000972	0	2	49588	1227820		1159610
FRWTNYFC	5157319100001192000971	0	2	49588	1296030		1227820
FRWTNYFC	5157319100001292000970	0	2	49588	1544545	1364245	1296030
FRWACOFC	5094319100000192000981	0	2	5950	15190	15190	0
FRWACOFC	5094319100000292000980	0	2	9918	35450		15190
FRWACOFC	5094319100000392000979	0	2	19835	70900		35450
FRWACOFC	5094319100000492000978	0	2	39670	116475		70900
FRWACOFC	5094319100000592000977	0	2	59505	202560		116475
FRWACOFC	5094319100000692000976	0	2	59505	278525		202560
FRWACOFC	5094319100000792000975	0	2	59505	354485		278525
FRWACOFC	5094319100000892000974	0	2	59505	405130		354485
FRWACOFC	5094319100000992000973	0	2	59505	430450		405130
FRWACOFC	5094319100001092000972	0	2	59505	455770		430450
FRWACOFC	5094319100001192000971	0	2	59505	481090		455770
FRWACOFC	5094319100001292000970	0	2	59505	665149	506409	481090
FRAQUILA	5158319100002092000930	0	2	5950	144124		52400
FRPRCTOR	5159319100003092000901	0	2	990	90410		59400
FRPRCTOR	5159319100003192000900	0	2	7934	458000	369500	90410
FRGRGTWN	5162319100004092000904	0	2	500	43530		37100
FRGRGTWN	5162319100004192000903	0	2	2975	48130		43530
FRGRGTWN	5162319100004292000902	0	2	5950	214389	128996	48130
FRGRNGER	5163319100005092000922	0	2	1290	79400		65500
FRGRNGER	5163319100005192000921	0	2	5950	147150		79400
FRGRNGER	5163319100005292000920	0	2	11900	538275	239223	147150
FRSTLHSE	5161319100006092000919	0	2	5950	255260		235700
FRSTLHSE	5161319100006192000918	0	2	11900	368715		255260
FRSTLHSE	5161319100006292000917	0	2	19835	431311		368715
FRSTLHSE	5161319100006392000916	0	2	19835	470433		431311
FRSTLHSE	5161319100006492000915	0	2	19835	509555		470433
FRSTLHSE	5161319100006592000914	0	2	19835	548680		509555
FRSTLHSE	5161319100006692000913	0	2	19835	568240		548680
FRSTLHSE	5161319100006792000912	0	2	19835	587800		568240
FRSTLHSE	5161319100006892000911	0	2	19835	607360		587800
FRSTLHSE	5161319100006992000910	0	2	19835	1045872	626922	607360
FRBELTON	5160319100006092000919	0	2	5950	489610		457600
FRBELTON	5160319100006192000918	0	2	11900	681670		489610
FRBELTON	5160319100006292000917	0	2	19835	777700		681670
FRBELTON	5160319100006392000916	0	2	19835	841720		777700
FRBELTON	5160319100006492000915	0	2	19835	905740		841720
FRBELTON	5160319100006592000914	0	2	19835	969760		905740
FRBELTON	5160319100006692000913	0	2	19835	1001770		969760
FRBELTON	5160319100006792000912	0	2	19835	1033780		1001770
FRBELTON	5160319100006892000911	0	2	19835	1065790		1033780
FRBELTON	5160319100006992000910	0	2	19835	1964900	1097800	1065790
FRSMRVLE	5164319100007092000906	0	2	1984	221140		160110
FRSMRVLE	5164319100007192000905	0	2	4960	813931	499167	221140

4.6.6 Downstream Flood Flow Discharge Limits

The downstream FF record rights are shown in Table 4.16. The first three FF record rights in Table 4.16 are located at control points corresponding to the Brazos River stream gages near Waco, Bryan, and Richmond. These three FF records set a maximum allowable discharge target of 119,010 ac-ft per day or 60,000 cfs. Whitney, Waco, and Aquilla are upstream of the stream gage near Waco. All flood control reservoirs in the model except Somerville are upstream of the stream gage near Bryan. All flood control reservoirs in the model are upstream of the stream gage near Richmond. The fourth FF record right is located at the control point corresponding to the stream gage on the Leon River near Gatesville. The maximum allowable discharge target is set to 9.917.5 ac-ft per day or 5,000 cfs. Proctor Lake is the only flood control reservoir upstream of the Gatesville gage FF record right. The fifth FF record right is located at the control point corresponding to the stream gage on the Little River near Cameron. The maximum allowable discharge target is set to 19,835 ac-ft per day or 10,000 cfs. All flood control reservoirs in the Little River watershed are located upstream of this FF record right. The sixth FF record right shown is located at the control point corresponding to the stream gage on the Little River near the town of Little River. The maximum allowable discharge target is set to 19,835 ac-ft per day or 10,000 cfs. Proctor, Belton, and Stillhouse are located upstream of this FF record right. The maximum allowable discharge is modulated between 5,950.5 ac-ft per day, 11,901 ac-ft per day, and 19,835 ac-ft per day.

The sixth FF record right is also connected to a drought index, DI/IS/IP, record set that summarizes the storage contents in Proctor, Belton, and

Stillhouse Hollow. The DO record shown in Table 4.16 applies to the sixth FF record and switches consideration of the drought index to a daily basis in the target-building steps that are detailed in the *Supplemental Manual*. The DI/IS/IP records are based on the maximum allowable discharge in Table 3.7 for the Little River near Little River stream gage.

Table 4.16 FF Record Representation of Flood Control Gages

```
FFBRWA41       43438650.   NDAYS       1
FFBRBR59       43438650.   NDAYS       3
FFBRRI70       43438650.   NDAYS       3
**
FFLEGT47        3619888.   NDAYS       1
FFLRCA58        7239775.   NDAYS       3
FFLRLR53        7239775.   NDAYS       1       2
DO            15
**
**
DI     2       3  PRCTOR  BELTON  STLHSE
IS     7       0  835280  835281 1423800 1423801 2094222 3468722
IP            30      30      60      60     100     100     100
```

The maximum allowable streamflow discharge rates per the USACE flood control operating schedule for the Brazos River Basin are summarized in Table 4.17 with respect to the SIMD FF record rights. Regulated flow at the FF record locations during the current or forecast simulation will trigger the upstream flood control reservoirs to impound all regulated flow at the flood control reservoir location. The maximum allowable release rates of the FR record rights are summarized in Table 4.18. Regulated flow and controlled releases will not exceed these limits at the location of the flood control reservoir if sufficient storage capacity is available.

Table 4.17 Maximum Allowable Discharge at the Location of the FF Record Rights

	Brazos River at Waco, BRWA41	Brazos River at Bryan, BRBR59	Brazos River at Richmond, BRRI70	Leon River at Gatesville, LEGT47	Little River at Little River, LRLR53	Little River at Cameron, LRCA58
cfs	60,000	60,000	60,000	5,000	10,000	10,000
ac-ft per day	119,010	119,010	119,010	9,918	19,835	19,835

Table 4.18 Maximum Allowable Release at FR Record Flood Control Reservoirs

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
cfs	25,000	3,000	30,000	4,000	10,000	10,000	3,000	6,000	2,500
ac-ft per day	49,588	5,950	59,505	7,934	19,835	19,835	5,950	11,900	4,960

CHAPTER V

WATER AVAILABILITY SIMULATIONS

Daily flow patterns, routing parameters, routing methods, forecasting methods, forecasting parameters, and target-setting options are described in Chapters II, III, and IV. These input data and parameterizations are used in a simulation case study of the Brazos River Basin and San Jacinto-Brazos Coastal Basin WAM. The Authorized Use scenario, Bwam3, is the primary focus of this chapter. The Current Conditions scenario, Bwam8, is used only to illustrate the effect of simulation time step on return flows. The objective of the simulation case study is to provide simulation results and to make comparisons for various daily simulation parameterizations. Water right reliability, reservoir storage, regulated flow, and unappropriated flow at the major reservoirs and selected stream gages are provided as a basis for comparison.

Simulation results in this chapter are organized according to the examination of the following aspects of a daily simulation:

- monthly versus daily simulation time step size,
- methods for disaggregating naturalized flow from monthly to daily values,
- placement of routed changes to flow,
- methods for forecasting water availability,
- forecasting periods, and
- daily water right target distribution.

The following terms are used throughout this chapter for reporting and analyzing the simulation results:

- **Naturalized (unregulated) flows:** flows representing pre-development conditions and, in particular, flows that would exist without the affects of the water management conditions being simulated. Naturalized flows are read by SIM/SIMD as monthly input sequences at pertinent control points.
- **Regulated flows:** flows representing the physical water at a control point after consideration of all water rights in the priority sequence. Regulated flows are provided as output from SIM/SIMD for each time step of the simulation. Regulated flows are comprised of unappropriated flows, reservoir releases passing through the control point to a destination downstream, or that portion of the streamflow that is being passed to meet downstream water right needs.
- **Unappropriated flows:** flows at a control point that were not depleted or called for downstream passage by any water rights through the conclusion of the priority sequence. Unappropriated flows could potentially be depleted by adding a new junior water right to the simulation.
- **Available flow (water availability):** flow that can be depleted from the stream by a water right. Available flow is specific to the priority date of the water right. Whereas unappropriated flow is computed after all water rights have been executed for a particular time step, available flow is computed at the priority date of the water right during the time step.

- **Exceedance frequency:** the percentage of the total number of time steps in the simulation where a particular value is equaled or exceeded. TABLES reports of exceedance frequency values for naturalized, regulated, and unappropriated streamflow and reservoir storage are examined in this chapter.
- **Run-of-river water right:** a water right without access to reservoir storage. Run-of-river rights do not refill reservoir storage or receive water from reservoir storage during a period of streamflow availability shortage.
- **Reliability:** the probability, expressed as a percentage, of successfully meeting the water right target demand. Period reliability is computed as the number of time steps when the target was completely met divided by the total number of time steps when a target was applied. Volume reliability is computed as the volume of water diverted by a water right divided by the volume of the target.
- **Reservoir drawdown:** period during the simulation when reservoir storage is not equal to the maximum conservation storage capacity. Reservoir drawdown volume is equal to the storage maximum storage capacity minus the storage contents of the particular time step.
- **Target:** diversion, instream flow, or hydropower generation demand, need, or requirement associated with a water right.

The selected control points listed in Table 4.1 are used in this chapter to report simulation results. No control points upstream of Possum Kingdom Lake or any control points located in the San Jacinto-Brazos Coastal Basin are included in the list of selected control points. Control points upstream of

Possum Kingdom Lake and within the San Jacinto-Brazos Coast Basin lie outside of the area represented in the SUPER flow data being utilized for flow pattern disaggregation of the monthly Bwam naturalized flow sequences.

All control points upstream of Possum Kingdom Lake are assigned the same SUPER flow pattern as assigned to the control point for Possum Kingdom. No routing parameters are calibrated for control points above Possum Kingdom because the flow pattern does not change. The changes to flow caused by water rights upstream of Possum Kingdome Lake will cascade downstream to Possum Kingdom Lake within the same time step as the change was made. Changes to flow begin to route downstream as they pass through the control point of Possum Kingdom Lake. The stream reaches upstream of Possum Kingdom Lake to the headwaters of the Brazos River should be calibrated for routing parameters if the water rights and regulated flows of that watershed are to be studied.

All control points in the San Jacinto-Brazos Coastal Basin are simulated using the uniform flow distribution method of disaggregating monthly naturalized flow sequences. No flow pattern data are developed for the coastal basin control points, and no output results are considered from the coastal basin.

The selected control points listed in Table 4.1 contain the control point locations of the 12 major BRA reservoirs. These 12 control point locations are utilized when summarizing reliabilities of water rights with BRA reservoir access. Reliability of water rights with access to reservoir storage is compared against the reliability of run-of-river water rights throughout the basin below Possum Kingdom Lake.

Water right reliabilities are also reported for the categories listed in Table 4.11. Reliability reporting for the categories in Table 4.11 allows comparison of water availability at various levels within the priority order. In scenarios 5.17 and 5.19, all water rights in the Bwam DAT file are assigned forecasting periods based on the criteria in Table 4.11. However, rather than reporting the water right reliabilities for all water rights in the Bwam DAT file, only certain water rights are selected for reporting in this chapter. Of the 1,643 WR record rights in the Bwam3 DAT file, only water rights that fit the following selection criteria are considered for examination of their reliability:

- not located within the San Jacinto-Brazos Coast Basin,
- not located upstream of Possum Kingdom Lake,
- no access to primary or secondary reservoir storage, and
- target demands not modified by water right backups, TO, or DI/IS/IP records.

Selection of water rights based on location ensures that only the water rights within the area covered by the SUPER flow data are included in the reliability tables. Selection based on target-setting quantities ensures that the water rights within each grouping have a consistent annual target demand regardless of the changes made to the SIMD simulation parameters. Table 5.1 presents the number of water rights in the Bwam3 dataset that fit the criteria above.

Table 5.1 Selected Run-of-river Water Rights for Reliability Reporting

Brazos Basin Rights below Possum Kingdom, According to Table 4.11 Criteria	Number of Water Rights	Total Annual Target, ac-ft per year
Dec. 31, 1929, and Senior Priority, all uses	45	120,722
Jan. 1, 1930, to Dec. 31, 1939, all uses	14	75,550
Jan. 1, 1940, to Dec. 31, 1949, all uses	25	191,981
Jan. 1, 1950, to Dec. 31, 1959, all uses	117	112,238
Jan. 1, 1960, to Dec. 31, 1969, all uses	231	125,777
Jan. 1, 1970, to Dec. 31, 1979, all uses	16	4,692
Jan. 1, 1980, and Junior Priority, municipal use	1	75,000
Jan. 1, 1980, and Junior Priority, non-municipal use	53	84,261
All Selected Water Rights	502	790,221

Negative incrementals found when comparing river flows at upstream and downstream sites are physically caused by time lag and attenuation effects as well as channel losses and other factors. Negative incremental flows are an important consideration in a conventional monthly SIM simulation and are an even greater concern with a daily time step SIMD simulation since opportunities for negative incrementals to occur increase with smaller time intervals.

Naturalized, regulated, and unappropriated flow volumes, other related variables, and SIM and SIMD algorithms are all based on cumulated total flows at each control point, rather than incremental local flows. However, the term negative incremental flow is applied to describe situations in which the naturalized flow volume for a particular time step at a control point is less than concurrent flows at control points located upstream.

All simulations conducted in this research use the JD record negative incremental option ADJINC 4. ADJINC 4 involves a flow adjustment defined as the minimum amount of flow that must be added to the naturalized flow at a control point to alleviate all negative incremental naturalized flows at upstream control points. SIM computes these adjustments for monthly flows. SIMD similarly computes negative incremental flow adjustments for whatever time step is being used in the simulation. SIMD first determines daily naturalized flows at all control points and then uses the daily flows to compute adjustment amounts where negative incrementals are found to occur. SIMD applies daily negative incremental flow adjustments in determining streamflow water availability in the same manner as SIM. In determining streamflow water available at a particular control point, the adjustment amounts are added to control point flows at downstream control points but not at the control point of the water right.

Utilizing a negative incremental adjustment is an important component of calculating water availability, particularly with sub-monthly time step simulations. Elevated water availability at the control point location of a water right can occur as flow from storm events routes downstream. Downstream locations may have lower water availability for several days until storm flows route downstream. However, upstream water rights should be able to divert a portion of the elevated flows while they reside in the upper watershed.

Negative incremental adjustments provide water rights the ability to divert water under the assumption that a portion of a flow wave should be available to both upstream and downstream water rights as it moves across the basin. For the same reason, flow forecasting is an important consideration in a sub-monthly time step simulation. Upstream junior water rights should limit their diversion of a flow wave by an appropriate amount so as not to injure the future water availability of downstream water rights as the flow wave moves into downstream areas of the basin.

5.1 Simulation Scenarios

Nineteen different simulation scenarios are considered in this chapter to examine the effect on simulation results for various SIMD parameterizations. To facilitate identification of these scenario results, each unique simulation parameter set is assigned a numerical scenario identifier. The scenario identifier begins with the chapter number. The scenario identifier decimal is incremented for each unique simulation parameter set. All scenario identifiers are given in Table 5.2. The identifiers of the scenarios being considered in each section of this chapter are provided at the beginning of the section. These nineteen different simulation scenarios are representative of only a small fraction of the possible combinations of methods and parameterizations possible in SIMD. However, the selection is intended to focus on specific aspects of the available methods and parameterizations in SIMD in order to highlight the possible effects on simulation results.

Table 5.2 Parameters per Chapter V Simulation Scenario

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.01	month	Bwam3	na	na	na	na	na	na
5.02	month	Bwam8	na	na	na	na	na	na
5.03	day	Bwam3	no routing	na	uniform	uniform	0 days	na
5.04	day	Bwam8	no routing	na	uniform	uniform	0 days	na
5.05	day	Bwam3	no routing	na	linear interp	uniform	0 days	na
5.06	day	Bwam3	no routing	na	daily pattern	uniform	0 days	na
5.07	day	Bwam3	lag-att	1	uniform	uniform	0 days	na
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na
5.09	day	Bwam3	lag-att	2	daily pattern	uniform	0 days	na
5.10	day	Bwam3	lag-att	1	daily pattern	uniform	1 day	1
5.11	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	1
5.12	day	Bwam3	lag-att	2	daily pattern	uniform	3 days	6
5.13	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	3
5.14	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	5
5.15	day	Bwam3	lag-att	1	daily pattern	uniform	5 days	1
5.16	day	Bwam3	lag-att	1	daily pattern	uniform	7 days	1
5.17	day	Bwam3	lag-att	1	daily pattern	uniform	Table 4.11	1
5.18	day	Bwam3	lag-att	1	daily pattern	Table 4.12	0 days	na
5.19	day	Bwam3	lag-att	1	daily pattern	Table 4.12	Table 4.11	1

5.2 Monthly versus Daily Simulation Time Steps

Time step size is isolated as the only variable between simulation scenarios. The daily SIMD simulation is performed with the default simulation settings, which include no routing, uniform monthly to daily flow disaggregation, and uniform daily target demands. The SIM and SIMD simulations differ only in the number of their respective time steps over the 1940 to 1997 Bwam period of record. The SIM simulation has 696 monthly time steps. The SIMD simulation has 21,185 daily time steps. The monthly SIM and daily SIMD simulations are conducted with JD record negative incremental option ADJINC 4.

The simulation scenarios being considered in this section are listed in Table 5.3. Scenarios 5.01 and 5.02 are conducted with monthly simulation time steps. All other simulations presented in this dissertation are conducted with daily simulation time steps.

Table 5.3 Parameters per Simulation Scenario Being Considered in Section 5.2

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.01	month	Bwam3	na	na	na	na	na	na
5.02	month	Bwam8	na	na	na	na	na	na
5.03	day	Bwam3	no routing	na	uniform	uniform	0 days	na
5.04	day	Bwam8	no routing	na	uniform	uniform	0 days	na

The flow-frequencies of the monthly aggregated naturalized flows are the same for all scenarios presented in this section as well as all scenarios considered in this chapter. The monthly naturalized flow-frequencies are presented in Table 5.4. Only the daily naturalized flow-frequencies will vary according to the SIMD option for monthly to daily naturalized flow disaggregation. Flow disaggregation is examined in the next section of this chapter. Daily naturalized flow-frequencies with respect to the uniform interpolation and flow pattern methods of disaggregation are presented in Tables 4.5, 4.6, and 4.7. The coefficients of variation with respect to the uniform interpolation and flow pattern methods of disaggregation are presented in Table 4.6 and Figure 4.4.

Table 5.4 Flow Frequency for Monthly Naturalized Streamflows for the Bwam 1940-1997 Period of Record for All Scenarios in Chapter V, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
LRCA58	109858.4	170466.	0.0	1249.0	2706.4	5440.0	15032.	44799.	130473.	290433.	1403136.
BRBR59	335663.5	483897.	0.0	11161.7	17707.0	28172.8	60717.	158629.	402271.	810073.	4704312.
BRHE68	446578.6	588542.	1634.0	17422.0	30122.4	44643.0	89698.	229331.	581968.	1153505.	5723482.
BRRI70	487518.7	613002.	0.0	25401.7	39521.8	53887.8	111204.	257456.	653272.	1230723.	6135975.
BRGM73	508769.8	634290.	4.0	25991.5	42893.2	59767.2	121025.	269220.	676536.	1272971.	6254466.
515531	66122.9	137150.	0.0	0.1	284.1	2186.9	6883.	18404.	64389.	166332.	1794484.
515631	91156.0	178785.	0.0	781.5	2047.9	4459.1	10228.	29493.	95565.	237433.	2653863.
515731	113905.5	203559.	7.5	1767.3	3507.6	6777.5	16135.	46037.	130424.	277592.	2962997.
515831	6147.4	11987.	0.0	0.0	0.0	0.0	37.	988.	6582.	19446.	102561.
509431	29788.7	53352.	0.0	9.3	39.1	468.0	2860.	9933.	34692.	80535.	530557.
516531	19399.4	34018.	0.0	0.0	32.9	100.9	614.	3970.	21035.	62911.	240424.
515931	12070.5	28547.	0.0	0.0	0.4	56.4	495.	2450.	10841.	33218.	327284.
516031	41915.5	75191.	0.0	0.1	2.3	485.7	3336.	12710.	47382.	112448.	627569.
516131	19238.4	34306.	27.8	147.7	486.0	718.5	2122.	5988.	20984.	53075.	309090.
516231	4796.5	8418.	0.0	0.0	19.7	85.3	344.	1416.	5510.	14484.	74909.
516331	15551.8	24898.	0.0	5.7	172.5	473.9	1773.	5412.	19756.	44908.	210085.
516431	18572.4	33188.	0.0	0.0	1.5	4.5	764.	3895.	18888.	60673.	250982.

5.2.1 Net Evaporation-precipitation

In the monthly simulation, net evaporation-precipitation is computed for the average of the beginning and ending reservoir surface areas per month. All target demands for the month are met in one time step, and the end-of-month reservoir storage volume is known. Beginning- and end-of-month surface areas are computed from an SV/SA record pair or by an equation specified on the WS record. In a daily simulation, there are between 28 and 31 beginning and end of period storages within the month. Reservoir net evaporation-precipitation is computed at each intermediate daily time step.

The total monthly net evaporation-precipitation volume from a reservoir is equivalent for daily and monthly time step simulations if the reservoirs are drawn down by the same volume per month. However, the summation of net evaporation-precipitation computed from daily average surface areas can result in an overall larger monthly draw on reservoir storage than computed by a singular time step as in the monthly simulation. The difference in net evaporation-precipitation is due to the computation of surface area from a non-linear relationship of reservoir surface area to storage volume using either a single monthly time step or 28 to 31 daily time steps. The relationship of surface area to storage volume typically follows the shape of a convex function. Figure 5.1 shows data from the SV/SA records of Belton Lake.

A larger draw on reservoir storage in the daily simulation causes slightly lower storage, which reduces surface area and reduces the draw on storage of net evaporation-precipitation in the subsequent month. The increased daily simulation drawdown due to increased net evaporation-precipitation is therefore self-limiting due to negative feedback. Slight differences in storage volume in all 719 reservoirs in the Bwam3 dataset cause small differences in the sequence of water availability between the SIM and SIMD simulations over the period of record.

Figure 5.2 shows the slight differences in reservoir storage in Belton Lake with respect to time step size. The differences are most evident during the peak drought months of the 1950s. The differences in storage contents between SIM and SIMD are returned to zero when the reservoir refills to the top of the conservation capacity in both simulation scenarios. Figure 5.3 shows the differences in total annual net evaporation-precipitation volume for Belton Lake. Again, the differences are most evident during the peak drought months.

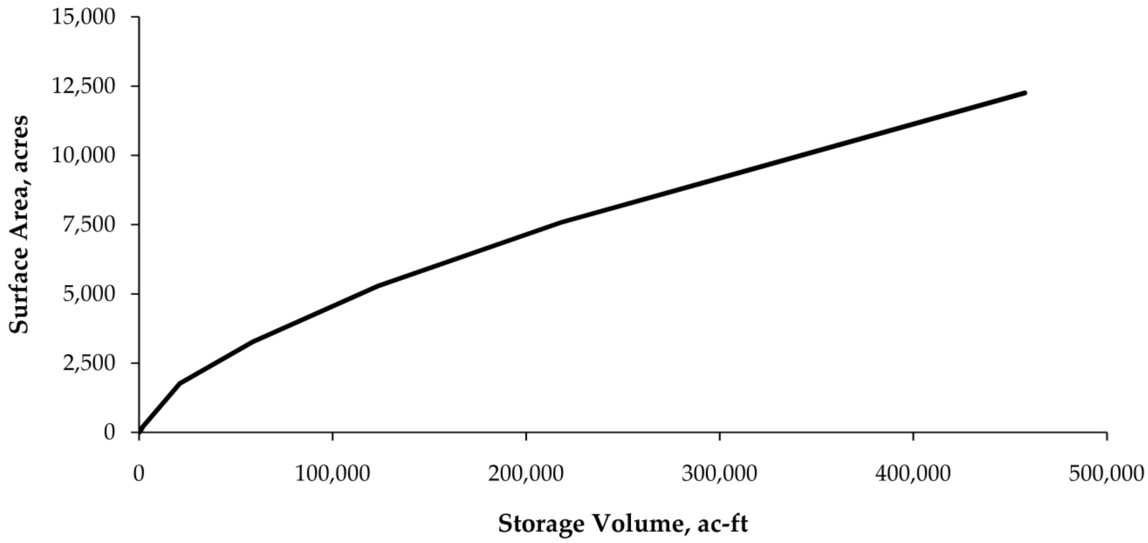

Figure 5.1 Bwam Surface Area versus Storage Volume for Belton Lake

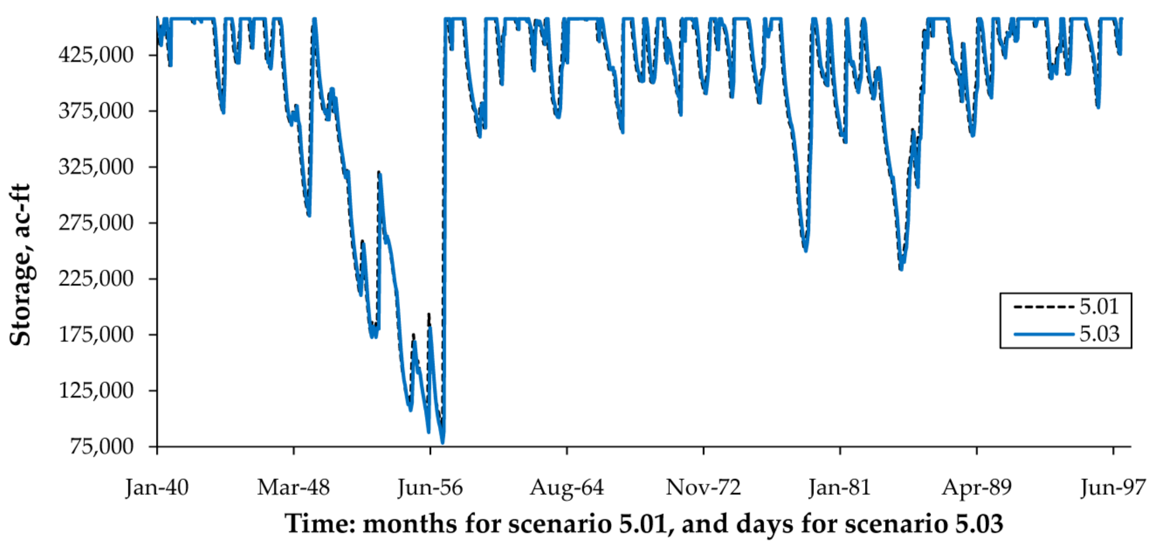

Figure 5.2 Storage in Belton Lake for Monthly versus Daily Simulation Using Uniformly Disaggregated Naturalized Flows

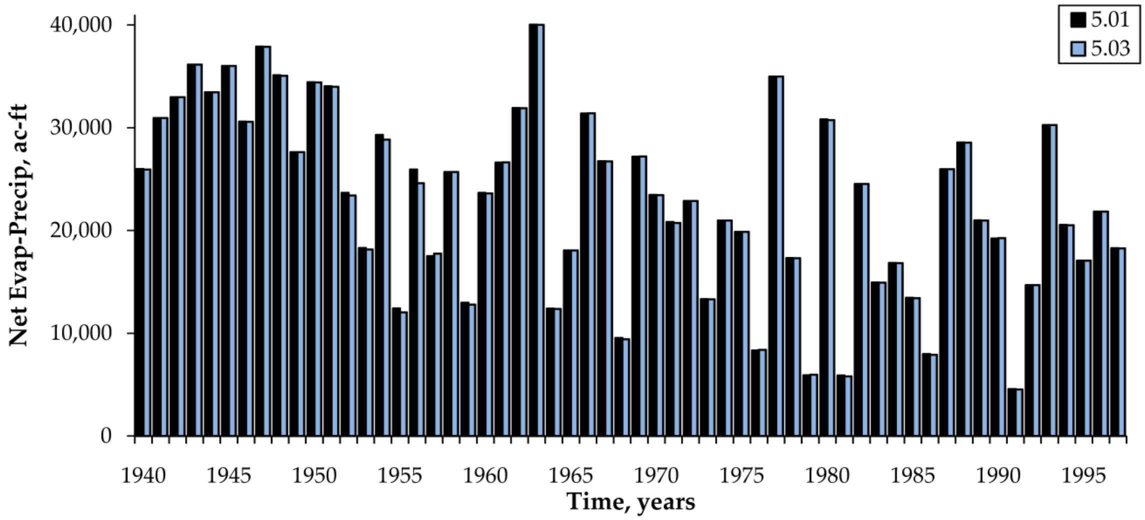

Figure 5.3 Net Evaporation-precipitation for Belton Lake for Monthly versus Daily Simulation Using Uniformly Disaggregated Naturalized Flows

Figure 5.4 shows the daily net evaporation-precipitation volume and storage volumes for Belton Lake in years 1955 and 1956. The difference at Belton in net evaporation-precipitation between the monthly and daily time step scenarios is greatest in 1956. The daily net evaporation-precipitation volumes are higher at the beginning of the month than at the end of the month as the reservoir is drawn down. This is particularly noticeable for July, August, and September 1956 at Belton. Net evaporation-precipitation depths are entered on the EV record in the EVA file and are distributed uniformly over the number of days in the month. The uniform distribution of the EV record data gives the stair-step appearance to the net evaporation-precipitation volume. The EV depths can be negative, as shown for May 1955 at Belton.

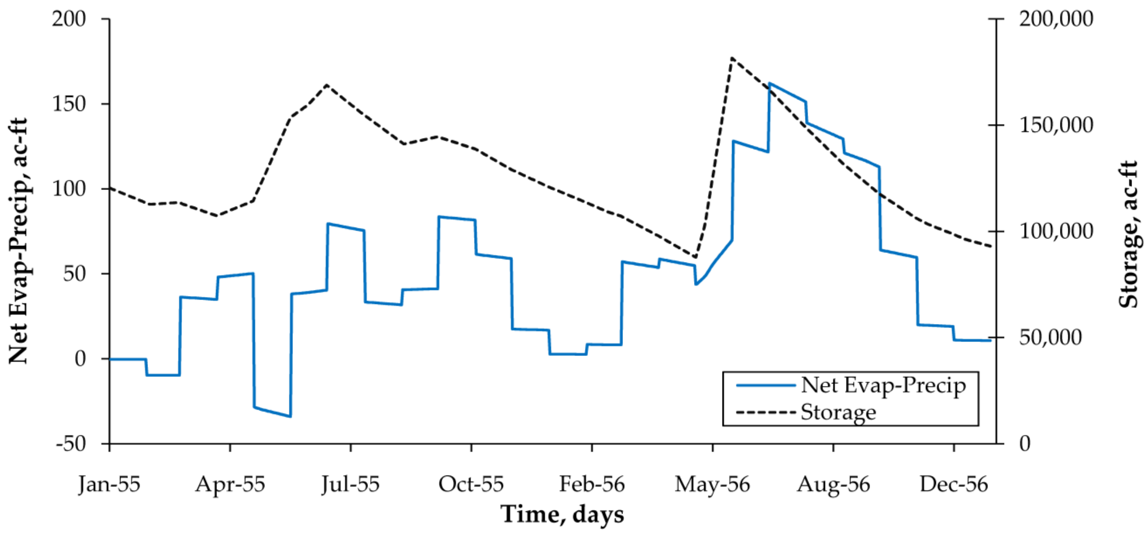

Figure 5.4 Belton Lake Net Evaporation-Precipitation and Storage, Scenario 5.03

5.2.2 Return Flows

Ordinary return flows are not simulated under the full authorization conditions in Bwam3. Return flows are simulated in Bwam8 for water right utilizations equivalent to current conditions. Differences occur between the monthly and daily simulations when the WR record return flow option RFMETH is set to place return flows in the stream at the beginning of the next time step. Bwam8 uses next-period placement of return flows. In the monthly simulation, the entire month's return flows are placed into the stream at the beginning of the next monthly time step. In the daily simulation, the return flows from day 1 of the month are placed into the stream at the beginning of day 2 of the same month. The next-period placement occurs within the same month in the daily simulation until the last day of the month. The differences in return flow timing between the monthly and daily simulation scenarios creates a difference in the sequence of water availability over the entire period of record.

Figure 5.5 shows the monthly total return flows entering the stream in Bwam8 at control point 100455 resulting from a municipal use water right on Belton Lake. Both sets of return flows sum to 1,780 ac-ft/yr in every year of the period of record.

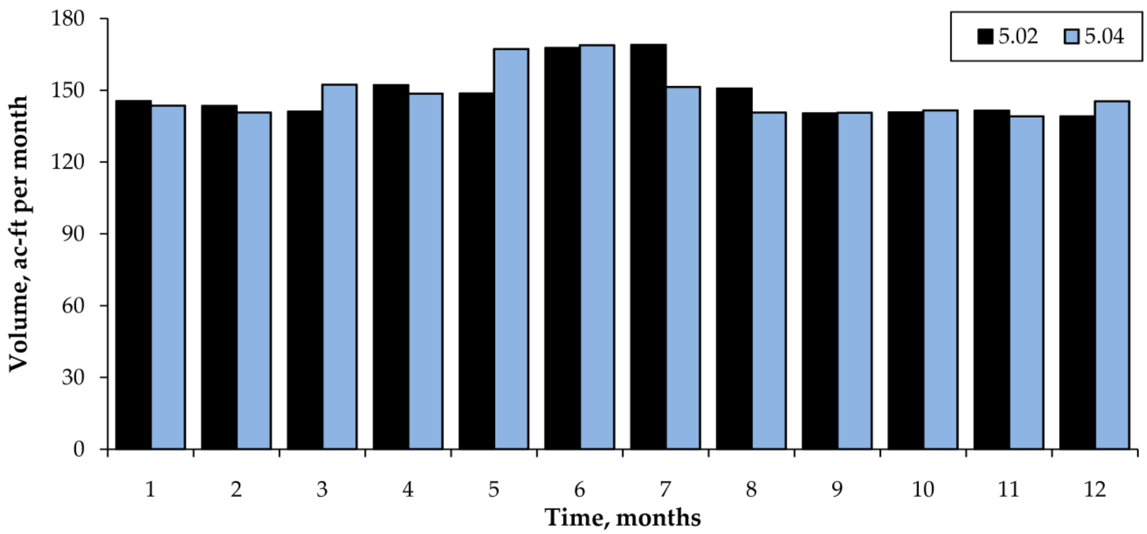

Figure 5.5 Monthly Total Return Flow Entering Control Point 100455

The RF records could be adjusted for specific use in SIMD. The existing RF records in the Bwam8 DAT file could be recomputed to ensure that the monthly aggregate pattern of return flow discharge for next-period placement is the same as the monthly pattern achieved in SIM. Adjustment of the RF records is not performed here.

The following tables compare the simulation output summaries between monthly and daily simulations for Authorized Use and Current Condition WAM datasets. End-of-month storage frequency, regulated flow frequency, unappropriated flow frequency, and a control point reliability summary are presented in Tables 5.5 though 5.12. Results for scenarios 5.01 and 5.03 are presented in Tables 5.5, 5.7, 5.9, and 5.11. Results for scenarios 5.02 and 5.04 are presented in Tables 5.6, 5.8, 5.10, and 5.12.

Water rights with access to BRA conservation storage in Whitney Lake are modeled with a DI/IS/IP record set to alter monthly target demands based on the state of conservation storage. The water right targets at Whitney's control point, 515731, are different between each simulation scenario due to target-setting differences based on reservoir storage.

The differences in Tables 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, and 5.12 are small but can be traced to the effect of time step size on the simulation computations. Slightly lower storage-frequencies in the Bwam3 scenarios due to the computation of net evaporation-precipitation with a non-linear surface-area-to-storage-volume relationship causes reservoir refilling to be slightly higher. This results in slightly lower regulated and unappropriated flow-frequencies. Reliabilities of water rights at the BRA conservation reservoirs are not materially affected. Water availability in the Bwam8 scenarios is higher overall due to the combination of lower water right demands and the presence of return flows. Reservoirs that are more frequently full in the monthly and daily simulations experience less divergence in their net evaporation-precipitation volumes.

Table 5.5 End-of-month Storage Frequency for Scenarios 5.01 and 5.03, ac-ft

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			Scenario 5.01, Monthly Bwam3 Simulation								
515531	668900.	74978.	271009.	472525.	530473.	571645.	637247.	697424.	724739.	724739.	724739.
515631	136235.	25563.	30631.	59945.	79936.	102904.	126190.	147316.	155000.	155000.	155000.
515731	591543.	54633.	366459.	410314.	472895.	516386.	574677.	608762.	631209.	636100.	636100.
515831	44579.	9682.	2011.	14788.	22103.	33203.	40452.	47339.	52400.	52400.	52400.
509431	165550.	40175.	53095.	64450.	79338.	96251.	144600.	179096.	199119.	201854.	206555.
516531	186786.	46721.	19773.	43996.	78038.	121425.	171559.	201445.	225400.	225400.	225400.
515931	47931.	13163.	2993.	11370.	18961.	28032.	41725.	52109.	59400.	59400.	59400.
516031	397450.	84760.	91488.	125201.	183613.	263842.	380235.	430234.	457600.	457600.	457600.
516131	191992.	63789.	0.	4329.	22162.	74014.	181269.	219386.	235700.	235700.	235700.
516231	29736.	9550.	0.	114.	7351.	16070.	25232.	33653.	37100.	37100.	37100.
516331	55843.	14300.	0.	10558.	23372.	35121.	51387.	62444.	65500.	65500.	65500.
516431	131827.	35010.	0.	35492.	59650.	76495.	116463.	145590.	160110.	160110.	160110.
Total	2648372.	390803.	1271876.	1494576.	1778397.	2105681.	2518298.	2779618.	2947680.	3001883.	3015578.
			Scenario 5.03, Daily Bwam3 Simulation								
515531	668795.	75139.	269543.	470428.	530457.	571647.	637245.	697424.	724739.	724739.	724739.
515631	136949.	24994.	30156.	63280.	80006.	102680.	126865.	148485.	155000.	155000.	155000.
515731	596544.	53159.	370680.	414703.	478367.	527948.	581982.	614835.	634468.	636100.	636100.
515831	44492.	9650.	2114.	14852.	22141.	33114.	40423.	47216.	52216.	52396.	52400.
509431	168256.	37264.	55251.	68443.	86026.	106637.	151505.	179938.	197338.	202061.	206562.
516531	186770.	46794.	21691.	42519.	76790.	121425.	171560.	201445.	225400.	225400.	225400.
515931	47858.	13221.	2919.	10832.	19004.	27797.	41671.	52161.	59400.	59400.	59400.
516031	396564.	86369.	78820.	117411.	179459.	262384.	378884.	429934.	457600.	457600.	457600.
516131	191643.	64262.	0.	3855.	20640.	71750.	181027.	219301.	235579.	235700.	235700.
516231	29215.	9816.	0.	103.	5307.	14374.	24862.	33209.	36607.	37081.	37100.
516331	55625.	14418.	0.	10114.	22166.	34661.	50855.	62201.	65500.	65500.	65500.
516431	131737.	35148.	0.	34867.	59560.	76364.	116413.	145590.	160110.	160110.	160110.
Total	2654447.	389864.	1273893.	1488608.	1773225.	2123049.	2529262.	2784987.	2950671.	3001954.	3015610.

Table 5.6 End-of-month Storage Frequency for Scenarios 5.02 and 5.04, ac-ft

CONTROL		STANDARD	% OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
POINT	MEAN	DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			Scenario 5.02, Monthly Bwam8 Simulation								
515531	542914.	19393.	427691.	475589.	500478.	520553.	543072.	551995.	552013.	552013.	552013.
515631	127140.	10269.	87162.	96274.	102524.	109941.	125690.	132821.	132821.	132821.	132821.
515731	529157.	29323.	405975.	431964.	464395.	486965.	518852.	542891.	549786.	549788.	549788.
515831	39067.	3383.	26620.	30852.	32211.	34052.	37050.	40685.	41700.	41700.	41700.
509431	193535.	16747.	109404.	144832.	159468.	171895.	186512.	200221.	205587.	206281.	206554.
516531	185904.	29135.	73361.	97847.	115396.	145777.	176596.	197096.	208017.	208017.	208017.
515931	47586.	8608.	14386.	25550.	29881.	36216.	42557.	50573.	54702.	54702.	54702.
516031	386383.	63612.	168110.	198125.	229757.	282554.	367191.	411973.	432978.	432978.	432978.
516131	191340.	48550.	34151.	48740.	66461.	110324.	179293.	214514.	224429.	224429.	224429.
516231	31604.	7147.	4385.	9369.	16498.	21718.	28228.	34637.	36980.	36980.	36980.
516331	48978.	3137.	32042.	37688.	42336.	45132.	48640.	50540.	50540.	50540.	50540.
516431	127131.	33581.	0.	36421.	56307.	75232.	112334.	140152.	154254.	154254.	154254.
Total	2450738.	227640.	1573222.	1745784.	1916415.	2153746.	2359741.	2528808.	2621593.	2643492.	2644770.
			Scenario 5.04, Daily Bwam8 Simulation								
515531	542909.	19474.	426373.	475606.	500456.	520615.	543052.	552012.	552013.	552013.	552013.
515631	127180.	10257.	87219.	96234.	102484.	110754.	125871.	132821.	132821.	132821.	132821.
515731	529473.	28866.	403991.	439684.	466337.	486431.	520356.	542944.	549788.	549788.	549788.
515831	39056.	3390.	26617.	30853.	32161.	34047.	37050.	40665.	41700.	41700.	41700.
509431	197575.	12954.	139975.	158720.	171818.	178594.	192680.	204237.	206289.	206391.	206562.
516531	185903.	29136.	73510.	97861.	115401.	145776.	176632.	197096.	208017.	208017.	208017.
515931	47482.	8682.	14208.	25374.	29813.	35694.	42285.	50425.	54702.	54702.	54702.
516031	385961.	64516.	163339.	193129.	226869.	280271.	366925.	411767.	432978.	432978.	432978.
516131	191183.	48718.	33590.	48138.	65921.	109838.	179398.	214505.	224429.	224429.	224429.
516231	31569.	7202.	4199.	9073.	16271.	21705.	28191.	34636.	36979.	36980.	36980.
516331	48953.	3181.	31881.	37609.	42194.	45035.	48595.	50540.	50540.	50540.	50540.
516431	127149.	33572.	0.	36416.	56392.	75347.	112341.	140154.	154254.	154254.	154254.
Total	2454394.	225034.	1577731.	1756770.	1917680.	2167210.	2367242.	2530149.	2623642.	2644404.	2644784.

Table 5.7 Flow Frequency of Monthly Regulated Flow for Scenarios 5.01 and 5.03, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								MAXIMUM
			100%	98%	95%	90%	75%	50%	25%	10%	
Scenario 5.01, Monthly Bwam3 Simulation											
LRCA58	82940.7	158828.	0.0	570.0	1189.9	1229.8	4009.7	17633.	86682.	236627.	1399448.
BRBR59	243301.9	438021.	0.0	1248.7	5463.0	9621.5	24289.0	71037.	263939.	656599.	4301499.
BRHE68	340324.4	536578.	0.0	9553.8	14834.8	21998.3	46765.9	116411.	432665.	958484.	5236145.
BRRI70	371315.4	564966.	0.0	14122.6	20314.9	28301.3	53914.7	133546.	461447.	1040992.	5633058.
BRGM73	340791.5	583988.	0.0	0.0	0.0	0.0	2461.5	85479.	447943.	1011849.	5689012.
515531	32457.3	111939.	0.0	0.0	0.0	0.0	0.0	0.	10993.	81423.	1599164.
515631	49124.2	151550.	0.0	0.0	0.0	0.0	0.0	1454.	28433.	133780.	2450764.
515731	64247.5	173159.	0.0	0.0	0.0	0.0	1676.0	9269.	42152.	170256.	2728846.
515831	4409.4	10931.	27.8	27.8	29.8	29.8	30.8	31.	2245.	15453.	100103.
509431	19986.8	50253.	0.0	0.0	0.0	0.0	0.0	0.	14515.	66688.	529065.
516531	11344.5	27698.	0.0	0.0	0.0	0.0	0.0	0.	2764.	45576.	215300.
515931	8450.2	26941.	0.0	0.0	0.0	0.0	0.0	37.	3137.	21842.	320839.
516031	27991.3	69704.	0.0	0.0	0.0	0.0	0.0	1498.	20497.	83931.	549161.
516131	12327.7	31839.	0.0	0.0	0.0	0.0	0.0	222.	7661.	39269.	305240.
516231	3513.9	7909.	0.0	0.0	0.0	0.0	0.0	150.	2699.	12223.	73211.
516331	11948.4	23648.	0.0	0.0	0.0	0.0	0.0	1730.	12464.	39255.	208215.
516431	13203.3	30339.	0.0	0.0	0.0	0.0	0.0	0.	7106.	52326.	247496.
Scenario 5.03, Daily Bwam3 Simulation											
LRCA58	82981.6	158584.	0.0	569.0	1190.0	1229.8	4359.1	17741.	86562.	235470.	1399445.
BRBR59	243380.0	437807.	0.0	1218.7	5463.1	9716.9	24132.9	71527.	263560.	655937.	4201400.
BRHE68	340401.5	536244.	0.0	9326.8	14744.6	22196.3	46497.0	116432.	436084.	959441.	5143402.
BRRI70	371394.1	564865.	0.0	13996.2	20080.5	28285.7	53445.0	132457.	466887.	1037857.	5547540.
BRGM73	341067.1	583781.	0.0	0.0	0.0	0.0	2840.2	84972.	452144.	1025522.	5605781.
515531	33292.4	111883.	0.0	0.0	0.0	0.0	0.0	0.	14028.	83856.	1592896.
515631	49901.0	151510.	0.0	0.0	0.0	0.0	0.0	1677.	29237.	140266.	2443846.
515731	64794.0	173781.	0.0	0.0	0.0	0.0	1371.5	9174.	41989.	175765.	2721641.
515831	4410.7	10930.	27.8	27.8	29.8	29.8	30.8	31.	2347.	15453.	100103.
509431	19622.5	49675.	0.0	0.0	0.0	0.0	0.0	9.	13459.	66920.	527645.
516531	11348.9	27708.	0.0	0.0	0.0	0.0	0.0	0.	2941.	45576.	215300.
515931	8488.0	26892.	0.0	0.0	0.0	0.0	0.0	105.	3301.	21842.	319994.
516031	28033.3	69493.	0.0	0.0	0.0	0.0	0.0	1768.	20267.	84000.	547716.
516131	12336.9	31777.	0.0	0.0	0.0	0.0	0.0	404.	7320.	38538.	302676.
516231	3518.0	7893.	0.0	0.0	0.0	0.0	0.0	165.	2643.	12203.	73211.
516331	11955.4	23604.	0.0	0.0	0.0	0.0	104.8	1773.	12449.	39177.	208215.
516431	13225.4	30347.	0.0	0.0	0.0	0.0	0.0	0.	7106.	52326.	247489.

Table 5.8 Flow Frequency of Monthly Regulated Flow for Scenarios 5.02 and 5.04, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.02, Monthly Bwam8 Simulation											
LRCA58	90963.9	162551.	1111.6	1229.8	2655.9	3995.3	8816.4	23271.	98855.	254307.	1406391.
BRBR59	280548.3	465742.	0.0	6945.2	11904.2	17180.1	37054.5	99074.	319442.	705735.	4622464.
BRHE68	381959.2	566323.	7125.5	15841.0	20136.5	29764.4	59069.2	153360.	497622.	1083354.	5605231.
BRRI70	421421.6	593326.	0.0	19009.9	27483.0	38212.4	74186.9	177344.	559829.	1136437.	6016152.
BRGM73	398670.4	613547.	0.0	0.0	0.0	0.0	35197.7	147906.	531416.	1139767.	6076411.
515531	49631.4	128816.	0.0	0.0	0.0	0.0	0.0	3796.	43063.	134837.	1783356.
515631	69468.5	170527.	0.0	0.0	0.0	0.0	0.0	9683.	67902.	195653.	2635168.
515731	84661.8	192842.	0.0	0.0	0.0	0.0	3771.5	15423.	79931.	237619.	2908978.
515831	5375.0	11773.	27.8	27.8	29.8	29.8	30.8	31.	5077.	17879.	101155.
509431	24055.9	52508.	0.0	0.0	0.0	0.0	0.0	609.	25516.	75856.	532892.
516531	13937.8	31155.	0.0	0.0	0.0	0.0	0.0	0.	10595.	52068.	235034.
515931	9104.9	27455.	0.0	0.0	0.0	0.0	0.0	25.	4362.	23457.	323096.
516031	29216.7	71394.	0.0	0.0	0.0	0.0	0.0	866.	22866.	87132.	610680.
516131	12955.4	32698.	0.0	0.0	0.0	0.0	0.0	1.	9227.	41876.	306248.
516231	3624.0	8032.	0.0	0.0	0.0	0.0	0.0	17.	3046.	13012.	73401.
516331	13883.1	24506.	0.0	0.0	0.0	0.0	645.5	3798.	16426.	42043.	210617.
516431	13383.3	30666.	0.0	0.0	0.0	0.0	0.0	0.	7465.	53145.	248174.
Scenario 5.04, Daily Bwam8 Simulation											
LRCA58	90981.8	162540.	1111.6	1229.8	2722.1	3982.2	8903.5	23148.	98908.	254127.	1406351.
BRBR59	280594.1	465836.	0.0	6623.6	11436.2	16743.0	36150.3	100317.	321791.	707000.	4618368.
BRHE68	381102.7	566162.	5735.5	15257.2	20298.9	28852.3	57957.5	151804.	496097.	1082096.	5599464.
BRRI70	420587.2	593084.	0.0	18793.6	27313.3	37610.4	73337.1	179291.	566609.	1134775.	6010528.
BRGM73	398038.1	613210.	0.0	0.0	0.0	0.0	33887.2	146053.	529430.	1137780.	6070934.
515531	49785.8	128576.	0.0	0.0	0.0	0.0	0.0	4475.	44836.	134388.	1782020.
515631	69594.8	170301.	0.0	0.0	0.0	0.0	0.0	9730.	68628.	195088.	2633413.
515731	84444.3	192779.	0.0	0.0	0.0	20.9	3437.0	15463.	80043.	235727.	2907281.
515831	5375.3	11769.	27.8	27.8	29.8	29.8	30.8	31.	5078.	17880.	101158.
509431	24424.8	52693.	0.0	0.0	0.0	0.0	0.0	1551.	25857.	75880.	533263.
516531	13941.2	31149.	0.0	0.0	0.0	0.0	0.0	0.	10595.	52291.	235025.
515931	9141.8	27427.	0.0	0.0	0.0	0.0	0.0	65.	4248.	24584.	322742.
516031	29256.2	71378.	0.0	0.0	0.0	0.0	0.0	878.	22856.	87008.	609806.
516131	12956.4	32692.	0.0	0.0	0.0	0.0	0.0	43.	9084.	41918.	306300.
516231	3624.4	8030.	0.0	0.0	0.0	0.0	0.0	56.	3034.	13012.	73401.
516331	13884.6	24501.	0.0	0.0	0.0	0.0	652.5	3793.	16432.	42050.	210662.
516431	13404.7	30684.	0.0	0.0	0.0	0.0	0.0	0.	7500.	53140.	248174.

Table 5.9 Flow Frequency of Monthly Unappropriated Flow for Scenarios 5.01 and 5.03, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
			Scenario 5.01, Monthly Bwam3 Simulation								
LRCA58	66752.5	153118.	0.0	0.0	0.0	0.0	0.0	0.	63569.	205292.	1392117.
BRBR59	182163.3	414906.	0.0	0.0	0.0	0.0	0.0	0.	183351.	549365.	4243700.
BRHE68	223506.3	481078.	0.0	0.0	0.0	0.0	0.0	1704.	228048.	746384.	4963221.
BRRI70	281299.3	528959.	0.0	0.0	0.0	0.0	0.0	36245.	365311.	894372.	5304625.
BRGM73	340791.5	583988.	0.0	0.0	0.0	0.0	2461.5	85479.	447943.	1011849.	5689012.
515531	24221.8	103187.	0.0	0.0	0.0	0.0	0.0	0.	0.	49440.	1599164.
515631	39686.4	145920.	0.0	0.0	0.0	0.0	0.0	0.	7273.	103874.	2450764.
515731	52513.3	170590.	0.0	0.0	0.0	0.0	0.0	0.	18716.	156654.	2728846.
515831	4022.1	10908.	0.0	0.0	0.0	0.0	0.0	0.	336.	15014.	100072.
509431	18965.4	50455.	0.0	0.0	0.0	0.0	0.0	0.	8357.	66688.	529065.
516531	10834.2	27298.	0.0	0.0	0.0	0.0	0.0	0.	701.	43874.	215300.
515931	6613.4	25523.	0.0	0.0	0.0	0.0	0.0	0.	0.	12384.	259583.
516031	25473.8	69409.	0.0	0.0	0.0	0.0	0.0	0.	7041.	81885.	549161.
516131	11447.6	31700.	0.0	0.0	0.0	0.0	0.0	0.	1462.	39269.	305240.
516231	3221.7	7907.	0.0	0.0	0.0	0.0	0.0	0.	1551.	11938.	73211.
516331	10778.7	23910.	0.0	0.0	0.0	0.0	0.0	0.	10993.	38739.	208215.
516431	12887.4	30275.	0.0	0.0	0.0	0.0	0.0	0.	6198.	52326.	247496.
			Scenario 5.03, Daily Bwam3 Simulation								
LRCA58	67553.6	152633.	0.0	0.0	0.0	0.0	0.0	0.	64110.	202314.	1392114.
BRBR59	197644.5	421949.	0.0	0.0	0.0	0.0	0.0	3316.	233856.	579434.	4143601.
BRHE68	252293.9	495618.	0.0	0.0	0.0	0.0	0.0	14874.	320476.	789467.	4870478.
BRRI70	282175.9	528399.	0.0	0.0	0.0	0.0	0.0	38357.	367979.	897935.	5219106.
BRGM73	341067.1	583781.	0.0	0.0	0.0	0.0	2840.2	84972.	452144.	1025522.	5605781.
515531	25268.9	103551.	0.0	0.0	0.0	0.0	0.0	0.	0.	56377.	1592896.
515631	41855.9	147319.	0.0	0.0	0.0	0.0	0.0	0.	12342.	115702.	2443846.
515731	55702.0	172649.	0.0	0.0	0.0	0.0	0.0	0.	24499.	168901.	2721641.
515831	4010.8	10879.	0.0	0.0	0.0	0.0	0.0	0.	383.	14754.	100072.
509431	18702.4	49593.	0.0	0.0	0.0	0.0	0.0	0.	8516.	66597.	527645.
516531	10953.7	27360.	0.0	0.0	0.0	0.0	0.0	0.	1155.	43804.	215300.
515931	6546.1	24987.	0.0	0.0	0.0	0.0	0.0	0.	0.	13655.	265977.
516031	25693.7	69190.	0.0	0.0	0.0	0.0	0.0	0.	11226.	81853.	547716.
516131	11459.5	31638.	0.0	0.0	0.0	0.0	0.0	0.	1824.	38538.	302676.
516231	3220.2	7891.	0.0	0.0	0.0	0.0	0.0	0.	1714.	11938.	73211.
516331	10794.1	23842.	0.0	0.0	0.0	0.0	0.0	0.	10748.	38173.	208215.
516431	13049.0	30381.	0.0	0.0	0.0	0.0	0.0	0.	6812.	52326.	247489.

Table 5.10 Flow Frequency of Monthly Unappropriated Flow for Scenarios 5.02 and 5.04, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.02, Monthly Bwam8 Simulation											
LRCA58	74630.8	157517.	0.0	0.0	0.0	0.0	0.0	3044.	79527.	220657.	1399060.
BRBR59	224158.6	442993.	0.0	0.0	0.0	0.0	0.0	25744.	254671.	633970.	4479736.
BRHE68	289581.5	527489.	0.0	0.0	0.0	0.0	0.0	48083.	366471.	892879.	5332307.
BRRI70	324578.0	559647.	0.0	0.0	0.0	0.0	0.0	78199.	433375.	978565.	5687719.
BRGM73	398670.4	613547.	0.0	0.0	0.0	0.0	35197.7	147906.	531416.	1139767.	6076411.
515531	39430.8	121101.	0.0	0.0	0.0	0.0	0.0	0.	24494.	107905.	1783356.
515631	59374.4	167618.	0.0	0.0	0.0	0.0	0.0	0.	43583.	171426.	2635168.
515731	74409.0	192897.	0.0	0.0	0.0	0.0	0.0	0.	59336.	221268.	2908978.
515831	5048.9	11769.	0.0	0.0	0.0	0.0	0.0	0.	4056.	16786.	101125.
509431	22951.3	52787.	0.0	0.0	0.0	0.0	0.0	0.	21265.	75856.	532892.
516531	13478.2	30801.	0.0	0.0	0.0	0.0	0.0	0.	9096.	51798.	235034.
515931	7589.3	26812.	0.0	0.0	0.0	0.0	0.0	0.	279.	17899.	315716.
516031	27753.7	71055.	0.0	0.0	0.0	0.0	0.0	0.	18982.	86876.	610680.
516131	12374.4	32509.	0.0	0.0	0.0	0.0	0.0	0.	8194.	41876.	306248.
516231	3459.9	8054.	0.0	0.0	0.0	0.0	0.0	0.	2627.	12712.	73401.
516331	12755.4	24867.	0.0	0.0	0.0	0.0	0.0	870.	15006.	41529.	210617.
516431	13302.2	30685.	0.0	0.0	0.0	0.0	0.0	0.	7146.	53145.	248174.
Scenario 5.04, Daily Bwam8 Simulation											
LRCA58	74494.0	157313.	0.0	0.0	0.0	0.0	0.0	3653.	79646.	218879.	1399020.
BRBR59	224243.5	442758.	0.0	0.0	0.0	0.0	0.0	26217.	254437.	635856.	4475640.
BRHE68	289133.3	527066.	0.0	0.0	0.0	0.0	0.0	46650.	365630.	890797.	5326540.
BRRI70	324073.1	559221.	0.0	0.0	0.0	0.0	0.0	76485.	431466.	978446.	5682094.
BRGM73	398038.1	613210.	0.0	0.0	0.0	0.0	33887.2	146053.	529430.	1137780.	6070934.
515531	38942.0	120171.	0.0	0.0	0.0	0.0	0.0	0.	24522.	103749.	1782020.
515631	59122.5	167106.	0.0	0.0	0.0	0.0	0.0	0.	43886.	171255.	2633413.
515731	74415.7	192736.	0.0	0.0	0.0	0.0	0.0	0.	62885.	221249.	2907281.
515831	5008.3	11736.	0.0	0.0	0.0	0.0	0.0	0.	4048.	16603.	101127.
509431	23292.9	52920.	0.0	0.0	0.0	0.0	0.0	0.	22743.	75880.	533263.
516531	13518.2	30790.	0.0	0.0	0.0	0.0	0.0	0.	9374.	51949.	235025.
515931	7414.3	26093.	0.0	0.0	0.0	0.0	0.0	0.	405.	17232.	290306.
516031	27826.3	71056.	0.0	0.0	0.0	0.0	0.0	0.	19530.	86518.	609806.
516131	12360.7	32502.	0.0	0.0	0.0	0.0	0.0	0.	7968.	41740.	306300.
516231	3447.3	8044.	0.0	0.0	0.0	0.0	0.0	0.	2623.	12444.	73401.
516331	12707.2	24807.	0.0	0.0	0.0	0.0	0.0	702.	15021.	41512.	210662.
516431	13316.5	30700.	0.0	0.0	0.0	0.0	0.0	0.	7146.	53140.	248174.

Table 5.11 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.01 and 5.03

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
				Scenario 5.01, Monthly Bwam3 Simulation							
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18886.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	94630.8	3230.14	91.67	96.59	91.7	91.8	92.0	92.2	99.1	99.7	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	438.04	98.85	99.35	98.9	99.0	99.1	99.3	99.3	99.3	99.6
516231	13610.0	237.10	97.99	98.26	98.0	98.1	98.1	98.1	98.3	98.3	98.4
516331	19840.0	66.35	99.43	99.67	99.4	99.4	99.4	99.6	99.6	99.6	99.6
516431	48000.0	51.99	99.71	99.89	99.7	99.7	99.7	99.7	99.9	99.9	100.0
Total	769082.2	4023.66		99.48							
				Scenario 5.03, Daily Bwam3 Simulation							
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18826.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	97843.6	2118.89	93.68	97.83	93.7	93.8	94.1	95.1	99.6	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	505.75	98.13	99.25	98.1	98.1	98.3	99.0	99.4	99.6	99.6
516231	13610.0	254.21	97.41	98.13	97.4	97.6	97.8	97.8	98.0	98.4	98.4
516331	19840.0	46.77	99.28	99.76	99.3	99.3	99.6	99.6	99.7	99.9	99.9
516431	48000.0	66.15	99.71	99.86	99.7	99.7	99.7	99.7	99.7	99.9	100.0
Total	772235.2	2991.79		99.61							

Table 5.12 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.02 and 5.04

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
			Scenario 5.02, Monthly Bwam8 Simulation								
515531	59482.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	36025.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18952.7	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	2394.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	45283.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516531	39337.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	14068.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	107737.5	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516231	11943.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516331	2569.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516431	48000.0	29.52	99.86	99.94	99.9	99.9	99.9	99.9	99.9	100.0	100.0
Total	453561.2	29.52		99.99							
			Scenario 5.04, Daily Bwam8 Simulation								
515531	59482.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	36025.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18891.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	2394.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	40323.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516531	39337.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	14068.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	107737.5	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516231	11943.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516331	2569.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516431	48000.0	30.12	99.86	99.94	99.9	99.9	99.9	99.9	99.9	100.0	100.0
Total	448539.7	30.13		99.99							

5.3 Methods for Disaggregating Naturalized Flow

SIMD has several alternative methods available to disaggregate monthly naturalized flows into daily naturalized flows. The user may also enter daily naturalized flows directly as input in lieu of selecting a disaggregation method. The uniform, linear interpolation, and flow pattern disaggregation methods are examined in this section. Flow disaggregation methods are discussed in Chapter IV of this dissertation. The focus of this section is to examine the effects of the naturalized flow disaggregation method on simulation output. The SUPER flow data presented in Chapter III are used as the basis for the flow pattern disaggregation in this chapter. The simulation scenarios being considered in this section are listed in Table 5.13.

Table 5.13 Parameters per Simulation Scenario in Section 5.3

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.03	day	Bwam3	no routing	na	uniform	uniform	0 days	na
5.05	day	Bwam3	no routing	na	linear interp	uniform	0 days	na
5.06	day	Bwam3	no routing	na	daily pattern	uniform	0 days	na
5.07	day	Bwam3	lag-att	1	uniform	uniform	0 days	na
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na

The SUPER daily flow patterns are used to develop routing parameters. Both the daily flow patterns and the associated routing parameters are used in Scenario 5.08. Scenario 5.07 uses routing parameters only as a basis for comparison with Scenario 5.08. The alternative methods for placing routed changes to flow will be examined in the next section.

The monthly naturalized flows are the same for all Bwam simulations in this chapter. Accordingly, the monthly naturalized flow-frequencies shown in Table 5.4 are the same for all scenarios. The flow frequency computed from daily naturalized flows will differ according to the method of disaggregation applied to the monthly naturalized flows. Table 4.5 shows the daily naturalized flow-frequencies for the uniform, linear interpolation, and flow pattern disaggregation methods used in the scenarios of this section.

Figure 5.6 shows daily disaggregated naturalized flow at the Bryan gage for 1952 for scenarios 7.03, 7.05, and 7.06. The visual appearance of the uniform and linear interpolation methods is most different where there are large intra-month changes in flow. Months with lower intra-month flow rate variability, such as September through November 1952, do not have as much difference in flow between the three methods of disaggregation. Lower intra-month flow variability allows the uniform and linear interpolation methods to create a more comparable set of disaggregated flows to the flow pattern method for that particular month. The algorithm of the linear interpolation method occasionally sets the end points of the interpolation splines below baseflow levels.

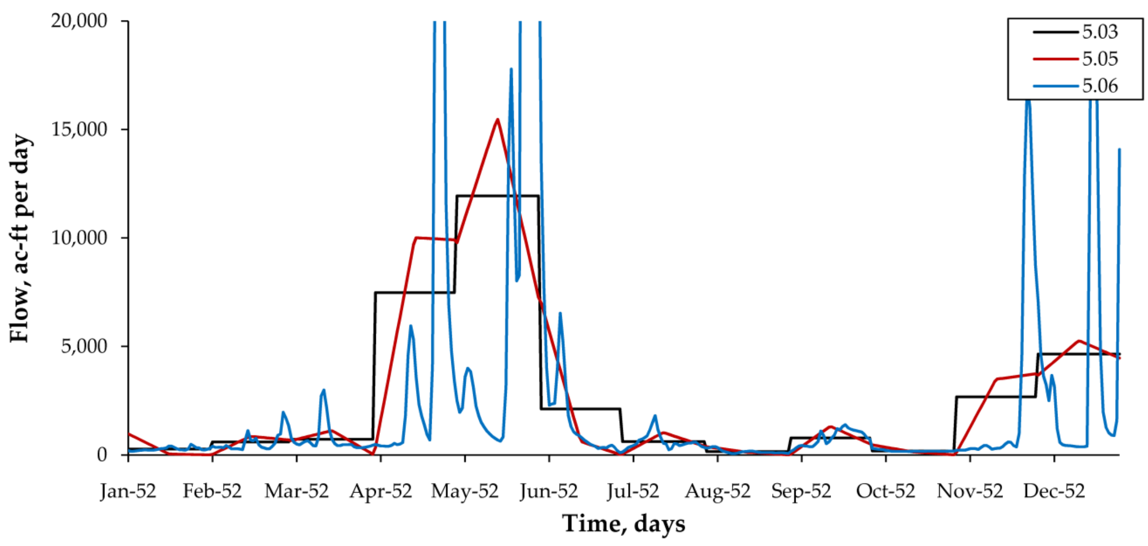

Figure 5.6 Daily Naturalized Flows at the Bryan Gage for 1952

Storage, regulated flow, and unappropriated flow frequency exhibit sensitivity to the disaggregation method used to create the input naturalized flow. Tables 5.14, 5.15, and 5.16 provide the end-of-day storage frequency, the daily regulated flow frequency, and the daily unappropriated flow frequency, respectively. Each table contains the frequencies for scenarios 5.03, 5.05, 5.06, and 5.08. Unappropriated flows are of particular importance to the consideration of new junior water rights. Table 5.16 shows that unappropriated flows are generally more concentrated in the higher magnitude flows for the flow pattern method of disaggregation. The flow pattern method creates higher peak naturalized daily flows and generally lower base and low daily naturalized flows than the uniform and linear interpolation methods. The greater positive skewness of daily naturalized flows derived from the flow pattern method was seen in the flow exceedance curves of Figures 4.5 and 4.6.

Table 5.14 End-of-Day Storage Frequency for Scenarios 5.03, 5.05, 5.06, and 5.08, ac-ft

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.03, Uniform Disaggregation											
515531	670092.	74287.	269543.	470828.	532982.	573341.	638530.	701242.	724739.	724739.	724739.
515631	137250.	24946.	25787.	62526.	80480.	102625.	127864.	149445.	155000.	155000.	155000.
515731	596889.	52882.	370485.	412583.	475983.	527297.	583508.	615663.	634414.	636100.	636100.
515831	44631.	9584.	2114.	14357.	22140.	33300.	40719.	47532.	52300.	52400.	52400.
509431	169140.	37377.	55251.	68667.	85565.	107876.	151655.	180725.	199025.	203378.	206562.
516531	187185.	46582.	21691.	45060.	76807.	121245.	171728.	202722.	224787.	225400.	225400.
515931	47999.	13154.	2919.	11049.	18951.	27959.	41829.	52163.	59400.	59400.	59400.
516031	396997.	86169.	78344.	118493.	178246.	260486.	379046.	430927.	457600.	457600.	457600.
516131	191895.	64184.	0.	4462.	21997.	70635.	181258.	219916.	235700.	235700.	235700.
516231	29323.	9842.	0.	31.	5504.	14458.	24831.	33423.	36866.	37100.	37100.
516331	55719.	14340.	0.	10103.	22272.	35230.	51011.	62572.	65500.	65500.	65500.
516431	132010.	34987.	0.	34811.	59651.	75743.	115767.	145479.	160110.	160110.	160110.
Total	2659131.	388704.	1273869.	1487142.	1776941.	2122294.	2531748.	2787958.	2954262.	3003584.	3015611.
Scenario 5.05, Linear Interpolation Disaggregation											
515531	665578.	75968.	266434.	467168.	523747.	561270.	634321.	693876.	724674.	724739.	724739.
515631	136529.	24858.	23567.	62001.	81733.	102668.	125213.	148264.	155000.	155000.	155000.
515731	596565.	52267.	370951.	414847.	476279.	529419.	582628.	615267.	633484.	636100.	636100.
515831	44171.	10047.	0.	10738.	20652.	33046.	40199.	47104.	52222.	52400.	52400.
509431	167244.	39199.	50794.	65385.	81124.	99204.	148119.	178789.	198717.	204032.	206562.
516531	185508.	47376.	18607.	41709.	73703.	119713.	168436.	200891.	223970.	225400.	225400.
515931	47317.	13326.	2963.	9875.	18662.	27157.	41500.	50690.	59399.	59400.	59400.
516031	394351.	86973.	69297.	111443.	176550.	261431.	375118.	426703.	457600.	457600.	457600.
516131	189033.	64158.	0.	2887.	20394.	68403.	175681.	215518.	234858.	235700.	235700.
516231	29015.	10025.	0.	0.	4443.	14296.	24326.	33037.	37100.	37100.	37100.
516331	55022.	15236.	0.	6589.	18398.	33147.	49745.	62110.	65500.	65500.	65500.
516431	130961.	35288.	0.	34478.	57712.	74972.	114762.	143840.	160102.	160110.	160110.
Total	2641295.	393896.	1263604.	1449322.	1744093.	2094998.	2511779.	2761596.	2941243.	2999936.	3015611.
Scenario 5.06, Flow Pattern Disaggregation without Routing											
515531	634269.	109172.	213139.	269077.	425116.	491078.	597295.	670381.	718704.	724739.	724739.
515631	137433.	23594.	30031.	65214.	88483.	103412.	128607.	147377.	154874.	155000.	155000.
515731	593772.	51816.	404201.	423941.	464666.	524154.	578458.	609137.	633187.	636100.	636100.
515831	35090.	16923.	0.	0.	0.	1657.	28153.	41068.	48079.	51229.	52400.
509431	154366.	47171.	12100.	36334.	52824.	76072.	132352.	168428.	193127.	200313.	206562.
516531	166557.	61376.	0.	0.	19963.	70192.	140484.	184886.	216570.	222710.	225400.
515931	39913.	18754.	0.	0.	0.	6021.	28672.	44417.	57209.	59400.	59400.
516031	365703.	124528.	0.	0.	27133.	179849.	340028.	412445.	455181.	457600.	457600.
516131	172166.	74093.	0.	0.	0.	543.	147076.	202376.	227231.	235700.	235700.
516231	25919.	12582.	0.	0.	0.	204.	18095.	31671.	36528.	37100.	37100.
516331	49978.	20476.	0.	0.	0.	12340.	43093.	59431.	65500.	65500.	65500.
516431	125759.	40883.	0.	279.	34855.	63666.	108925.	140113.	159462.	160110.	160110.
Total	2500926.	537291.	836559.	960486.	1121331.	1703584.	2346368.	2676144.	2891164.	2978481.	3015611.
Scenario 5.08, Flow Pattern Disaggregation with Routing											
515531	633117.	97579.	218468.	373546.	450143.	490128.	578876.	664988.	713850.	724541.	724739.
515631	133553.	26008.	36596.	57263.	72475.	97595.	121399.	143696.	154188.	155000.	155000.
515731	591271.	54946.	365112.	407255.	451365.	522237.	577696.	607028.	630332.	635745.	636100.
515831	41000.	11930.	0.	4316.	15564.	23926.	36055.	44638.	50164.	52071.	52400.
509431	158176.	47017.	8510.	38143.	57646.	80479.	135835.	172650.	195978.	201864.	206562.
516531	174609.	54500.	0.	20496.	47519.	90952.	151423.	191492.	218206.	222733.	225400.
515931	42500.	15823.	0.	3615.	7849.	18640.	33596.	44865.	56954.	59393.	59400.
516031	375705.	110735.	0.	17977.	94813.	212970.	355511.	416125.	452731.	457600.	457600.
516131	181743.	69537.	0.	0.	364.	37235.	165258.	209298.	231372.	235700.	235700.
516231	27344.	11111.	0.	0.	295.	9092.	20775.	31971.	36043.	37100.	37100.
516331	53377.	17266.	0.	1033.	11007.	27158.	48319.	61971.	65500.	65500.	65500.
516431	129898.	36067.	0.	30227.	55981.	71225.	113618.	142781.	159740.	160110.	160110.
Total	2542291.	479728.	957754.	1121952.	1442010.	1775366.	2367310.	2691557.	2900170.	2981422.	3015611.

Table 5.15 Flow Frequency of Daily Regulated Flow for Scenarios 5.03, 5.05, 5.06, and 5.08, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.03, Uniform Disaggregation											
LRCA58	2726.23	5259.1	0.00	17.65	39.67	39.67	131.38	576.0	2856.8	7892.2	48285.7
BRBR59	7995.87	14465.4	0.00	3.88	170.37	307.55	783.52	2177.8	8494.6	21486.7	145436.4
BRHE68	11183.36	17700.6	0.00	306.79	473.11	725.53	1487.41	3719.0	13511.9	30892.3	177567.3
BRRI70	12201.57	18636.2	0.00	429.23	632.40	891.40	1772.87	4201.5	15227.9	33634.4	190330.5
BRGM73	11205.23	19250.3	0.00	0.00	0.00	0.00	9.99	2735.7	14551.2	33616.8	191905.8
515531	1093.77	3713.4	0.00	0.00	0.00	0.00	0.00	0.0	209.8	2811.0	56722.2
515631	1639.42	5016.7	0.00	0.00	0.00	0.00	0.00	25.9	909.1	4851.8	84126.4
515731	2128.71	5770.9	0.00	0.00	0.00	0.00	19.47	256.6	1302.0	5976.0	93214.0
515831	144.91	370.0	0.96	0.99	0.99	0.99	0.99	1.0	47.8	512.5	3264.6
509431	644.67	1680.4	0.00	0.00	0.00	0.00	0.00	0.0	367.0	2268.0	17090.3
516531	372.85	966.9	0.00	0.00	0.00	0.00	0.00	0.0	29.1	1520.7	7585.4
515931	278.86	892.8	0.00	0.00	0.00	0.00	0.00	0.6	96.3	733.2	10860.8
516031	920.99	2329.2	0.00	0.00	0.00	0.00	0.00	44.6	576.9	2790.1	19715.9
516131	405.31	1067.0	0.00	0.00	0.00	0.00	0.00	1.6	191.3	1327.1	9955.5
516231	115.58	267.0	0.00	0.00	0.00	0.00	0.00	2.1	77.9	417.1	2496.6
516331	392.77	792.0	0.00	0.00	0.00	0.00	0.00	50.5	409.0	1279.8	6996.4
516431	434.50	1025.5	0.00	0.00	0.00	0.00	0.00	0.0	196.6	1750.5	8534.8
Scenario 5.05, Linear Interpolation Disaggregation											
LRCA58	2732.05	5543.3	0.00	0.00	19.91	39.67	106.68	548.8	2644.8	8376.1	71450.3
BRBR59	8027.23	15274.4	0.00	0.00	0.00	163.64	635.36	2059.3	8265.6	23064.3	197777.9
BRHE68	11212.53	18678.8	0.00	0.00	191.49	462.07	1220.83	3577.8	13533.1	31619.4	225866.0
BRRI70	12226.42	19573.6	0.00	13.91	384.15	664.58	1593.76	3948.7	15283.0	34041.9	246771.5
BRGM73	11312.18	20163.5	0.00	0.00	0.00	0.00	0.00	2464.9	14674.5	33878.2	249625.3
515531	1109.59	4022.1	0.00	0.00	0.00	0.00	0.00	0.0	144.1	2657.2	67261.4
515631	1666.59	5381.6	0.00	0.00	0.00	0.00	0.00	0.0	804.6	4378.6	108601.0
515731	2157.27	6149.8	0.00	0.00	0.00	0.00	0.00	222.2	1273.2	6097.4	119891.8
515831	145.05	408.7	0.52	0.99	0.99	0.99	0.99	1.0	30.1	501.7	5917.0
509431	646.30	1791.8	0.00	0.00	0.00	0.00	0.00	0.0	281.7	2144.1	27964.5
516531	373.42	1053.4	0.00	0.00	0.00	0.00	0.00	0.0	11.8	1450.8	13283.1
515931	279.79	968.0	0.00	0.00	0.00	0.00	0.00	0.4	76.5	679.8	16984.5
516031	923.35	2471.1	0.00	0.00	0.00	0.00	0.00	42.6	470.9	2970.9	30040.1
516131	406.71	1124.1	0.00	0.00	0.00	0.00	0.00	3.6	192.3	1271.0	16693.2
516231	115.82	282.9	0.00	0.00	0.00	0.00	0.00	3.2	68.9	408.9	4410.4
516331	393.79	839.4	0.00	0.00	0.00	0.00	0.00	45.6	388.5	1277.1	11638.3
516431	434.94	1131.4	0.00	0.00	0.00	0.00	0.00	0.0	87.6	1624.3	14140.0

Table 5.15 Continued

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.06, Flow Pattern Disaggregation without Routing											
LRCA58	2786.25	8815.1	0.00	0.00	15.67	39.67	70.35	408.3	1851.4	6531.8	289639.4
BRBR59	8240.11	21721.6	0.00	0.00	0.00	106.55	497.60	1429.4	6182.0	20651.2	703326.1
BRHE68	11415.31	24782.9	0.00	0.00	155.27	377.81	976.62	2766.5	10625.2	31199.6	743143.9
BRRI70	12409.83	25854.6	0.00	0.00	230.97	473.73	1167.67	2773.1	12027.8	33755.4	633759.6
BRGM73	11593.65	26691.1	0.00	0.00	0.00	0.00	0.00	1201.5	10931.7	33805.8	573955.6
515531	1168.93	6186.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1366.8	185366.7
515631	1835.29	7812.9	0.00	0.00	0.00	0.00	0.00	0.0	539.8	3192.8	168879.1
515731	2336.60	8625.1	0.00	0.00	0.00	0.00	0.00	157.2	976.7	4625.3	183944.1
515831	151.94	1096.5	0.00	0.00	0.00	0.99	0.99	1.0	1.5	76.9	37727.5
509431	657.31	3582.9	0.00	0.00	0.00	0.00	0.00	0.0	82.0	1107.8	219454.0
516531	384.39	2193.6	0.00	0.00	0.00	0.00	0.00	0.0	1.5	283.1	72191.0
515931	291.58	2256.5	0.00	0.00	0.00	0.00	0.00	0.0	16.2	383.6	200271.2
516031	950.44	3837.8	0.00	0.00	0.00	0.00	0.00	36.4	353.4	2202.6	163440.8
516131	426.85	2171.3	0.00	0.00	0.00	0.00	0.00	2.5	97.9	1016.8	116916.8
516231	119.31	630.7	0.00	0.00	0.00	0.00	0.00	3.4	47.1	258.7	26836.4
516331	402.74	1583.8	0.00	0.00	0.00	0.00	0.00	33.7	253.3	909.5	61175.4
516431	440.24	2134.6	0.00	0.00	0.00	0.00	0.00	0.0	18.1	714.9	98078.1
Scenario 5.08, Flow Pattern Disaggregation with Routing											
LRCA58	2756.22	8622.7	0.00	0.00	21.60	39.67	97.50	408.5	1864.7	6382.4	289130.7
BRBR59	8117.65	21589.2	0.00	0.00	98.88	219.76	575.50	1567.5	5858.2	20097.7	711444.9
BRHE68	11303.78	24501.7	0.00	144.52	310.77	514.66	1119.50	2716.4	10410.9	30664.7	750731.2
BRRI70	12313.41	25160.6	0.00	71.48	319.61	605.03	1397.62	2912.4	11854.8	33347.7	636331.9
BRGM73	11436.87	25868.9	0.00	0.00	0.00	0.00	0.00	1498.6	10873.6	32857.3	575855.3
515531	1156.11	5873.9	0.00	0.00	0.00	0.00	0.00	0.0	203.5	1647.5	155382.6
515631	1689.04	7322.5	0.00	0.00	0.00	0.00	0.00	47.2	547.3	2815.6	157099.3
515731	2196.45	8216.3	0.00	0.00	0.00	0.00	11.25	211.4	1014.6	4054.9	187870.6
515831	146.89	1072.5	0.00	0.96	0.99	0.99	0.99	1.0	4.4	96.5	37727.5
509431	648.06	3482.3	0.00	0.00	0.00	0.00	0.00	0.0	133.9	1138.2	219400.2
516531	379.20	2032.5	0.00	0.00	0.00	0.00	0.00	0.0	34.6	370.2	72120.4
515931	284.75	2151.7	0.00	0.00	0.00	0.00	0.00	1.6	51.6	401.5	197850.8
516031	930.19	3743.5	0.00	0.00	0.00	0.00	0.00	25.3	359.8	2130.1	164586.3
516131	416.10	2082.5	0.00	0.00	0.00	0.00	0.00	13.2	128.6	1023.5	120488.7
516231	116.87	570.8	0.00	0.00	0.00	0.00	0.00	3.2	50.6	270.0	23854.5
516331	396.02	1541.3	0.00	0.00	0.00	0.00	0.91	35.6	262.1	891.2	60136.2
516431	436.31	2166.2	0.00	0.00	0.00	0.00	0.00	0.0	15.9	677.4	98089.0

Table 5.16 Flow Frequency of Daily Unappropriated Flow for Scenarios 5.03, 5.05, 5.06, and 5.08, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			Scenario 5.03, Uniform Disaggregation								
LRCA58	2219.37	5076.1	0.00	0.00	0.00	0.00	0.00	0.0	2068.0	6827.7	48032.9
BRBR59	6493.30	13958.3	0.00	0.00	0.00	0.00	0.00	0.0	7220.7	19176.9	143571.9
BRHE68	8288.72	16384.0	0.00	0.00	0.00	0.00	0.00	395.0	10036.9	26225.1	168763.3
BRRI70	9270.45	17443.4	0.00	0.00	0.00	0.00	0.00	1169.2	11792.8	28892.0	179735.9
BRGM73	11205.23	19250.3	0.00	0.00	0.00	0.00	9.99	2735.7	14551.2	33616.8	191905.8
515531	830.17	3443.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1886.7	56722.2
515631	1375.11	4890.5	0.00	0.00	0.00	0.00	0.00	0.0	231.7	3659.6	84126.4
515731	1830.00	5729.2	0.00	0.00	0.00	0.00	0.00	0.0	628.3	5703.0	93214.0
515831	131.77	367.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	495.7	3263.6
509431	614.44	1676.5	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2263.4	17090.3
516531	359.87	954.9	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1454.5	7585.4
515931	215.06	849.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	443.1	10841.6
516031	844.12	2316.2	0.00	0.00	0.00	0.00	0.00	0.0	152.1	2767.3	19715.9
516131	376.48	1062.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1327.1	9955.5
516231	105.79	266.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	403.3	2496.6
516331	354.62	799.7	0.00	0.00	0.00	0.00	0.00	0.0	341.3	1263.6	6996.4
516431	428.70	1026.7	0.00	0.00	0.00	0.00	0.00	0.0	150.7	1750.5	8534.8
			Scenario 5.05, Linear Interpolation Disaggregation								
LRCA58	2181.46	5357.1	0.00	0.00	0.00	0.00	0.00	0.0	1779.9	7276.4	69427.1
BRBR59	6429.83	14648.0	0.00	0.00	0.00	0.00	0.00	0.0	6295.0	20532.9	177106.3
BRHE68	8330.76	17250.1	0.00	0.00	0.00	0.00	0.00	0.0	9776.6	26624.8	217062.0
BRRI70	9393.18	18350.1	0.00	0.00	0.00	0.00	0.00	732.7	11606.1	29195.5	236176.9
BRGM73	11312.18	20163.5	0.00	0.00	0.00	0.00	0.00	2464.9	14674.5	33878.2	249625.3
515531	792.37	3577.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1418.2	67261.4
515631	1342.00	5143.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	3474.7	108601.0
515731	1784.52	6027.3	0.00	0.00	0.00	0.00	0.00	0.0	66.5	5348.1	119891.8
515831	126.60	402.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	417.5	5916.0
509431	589.87	1770.8	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2032.0	27964.5
516531	350.30	1028.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1330.5	13283.1
515931	204.72	886.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	354.5	13368.5
516031	822.95	2448.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2820.7	30040.1
516131	365.37	1118.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1239.2	16693.2
516231	101.79	280.9	0.00	0.00	0.00	0.00	0.00	0.0	0.0	386.5	4410.4
516331	343.71	843.4	0.00	0.00	0.00	0.00	0.00	0.0	240.6	1243.5	11638.3
516431	425.62	1132.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1620.5	14140.0

Table 5.16 Continued

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.06, Flow Pattern Disaggregation without Routing											
LRCA58	1622.66	5865.0	0.00	0.00	0.00	0.00	0.00	0.0	420.4	4223.4	175409.2
BRBR59	4887.55	15322.1	0.00	0.00	0.00	0.00	0.00	0.0	2424.8	12843.3	492268.8
BRHE68	7737.08	20910.4	0.00	0.00	0.00	0.00	0.00	0.0	4887.0	23376.3	483573.0
BRRI70	9558.62	24257.3	0.00	0.00	0.00	0.00	0.00	0.0	7730.2	28753.7	583748.8
BRGM73	11593.65	26691.1	0.00	0.00	0.00	0.00	0.00	1201.5	10931.7	33805.8	573955.6
515531	431.71	3108.1	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	94552.0
515631	873.86	5029.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1062.1	150281.3
515731	1210.58	6022.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1983.3	153846.3
515831	59.24	560.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	21044.4
509431	339.98	1808.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	473.4	58651.4
516531	141.86	745.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2.0	13821.1
515931	94.30	634.1	0.00	0.00	0.00	0.00	0.00	0.0	0.0	25.2	20061.3
516031	586.53	2484.9	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1302.4	79437.0
516131	231.33	1026.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	555.9	41388.1
516231	70.11	341.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	196.8	14969.7
516331	239.32	1005.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	672.7	43911.1
516431	349.93	1780.1	0.00	0.00	0.00	0.00	0.00	0.0	0.0	467.8	59022.1
Scenario 5.08, Flow Pattern Disaggregation with Routing											
LRCA58	1823.96	6238.4	0.00	0.00	0.00	0.00	0.00	0.0	701.3	4820.8	177166.4
BRBR59	5072.60	15405.9	0.00	0.00	0.00	0.00	0.00	0.0	2837.7	13739.9	494806.2
BRHE68	7708.37	20419.8	0.00	0.00	0.00	0.00	0.00	0.0	5128.4	23450.9	484958.7
BRRI70	9416.94	23535.1	0.00	0.00	0.00	0.00	0.00	83.6	7689.8	28072.0	585699.9
BRGM73	11436.87	25868.9	0.00	0.00	0.00	0.00	0.00	1498.6	10873.6	32857.3	575855.3
515531	496.39	3380.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	13.8	88264.9
515631	941.66	5090.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1221.6	136725.1
515731	1307.64	6031.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2364.4	139327.5
515831	94.15	730.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	55.4	23145.8
509431	444.18	2164.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	832.0	66844.3
516531	158.96	815.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	72.2	29750.2
515931	113.58	736.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	59.3	27416.1
516031	665.55	2658.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1604.9	73944.9
516131	283.41	1245.5	0.00	0.00	0.00	0.00	0.00	0.0	0.0	787.5	72658.6
516231	92.05	436.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	246.3	15600.2
516331	298.98	1209.5	0.00	0.00	0.00	0.00	0.00	0.0	61.1	788.6	43911.1
516431	399.55	1938.1	0.00	0.00	0.00	0.00	0.00	0.0	0.0	607.6	59209.9

Figure 5.7 shows daily storage sequences at Belton Lake for scenarios with uniform, linear interpolation, and flow pattern disaggregation. The uniform and linear interpolation methods generally produce similar storages for Belton. However, the flow pattern method results in substantially less storage during the peak of the 1950s' drought. Similar divergence in storage contents for scenario 5.06 is seen in the drawdown of 1964. Belton reached nearly the same

level of drawdown in 1978 between all three scenarios. Drawdown in 1984 was somewhat similar between the three scenarios.

Belton's conservation storage is used as backup for 112,257 ac-ft per year of target demands. Belton can refill up to the top of conservation with a December 16, 1963, priority date.

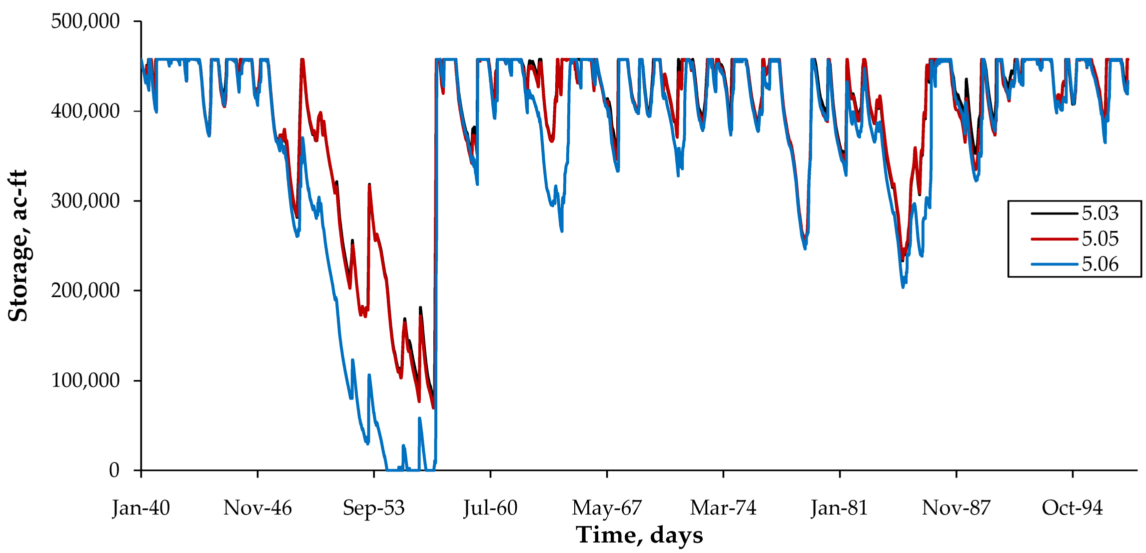

Figure 5.7 Daily Storage in Belton Lake for Scenarios 5.03, 5.05, and 5.06

Figure 5.8 shows the daily storages at Waco Lake for scenarios with uniform, linear interpolation, and flow pattern disaggregation. Like Belton, the uniform and linear interpolation methods of disaggregation produce very similar storage results for Waco Lake. The largest differences between the uniform and linear interpolation methods and the flow pattern methods occur during the peak of the 1950s' drought. Waco's conservation storage is used as backup for 97,335 ac-ft per year of target demands. Unlike Belton, Waco has multiple priority dates for refilling pools. The senior-most pool in Waco Lake has 39,100 ac-ft of conservation storage and can refill with a priority of January 10, 1929. The top-most pool in Waco Lake has 14,400 ac-ft of conservation storage and refills with the junior-most priority date in the basin. Figure 5.8 shows that the junior-most pool in Waco Lake often cannot completely refill even outside of drought periods in scenario 5.06.

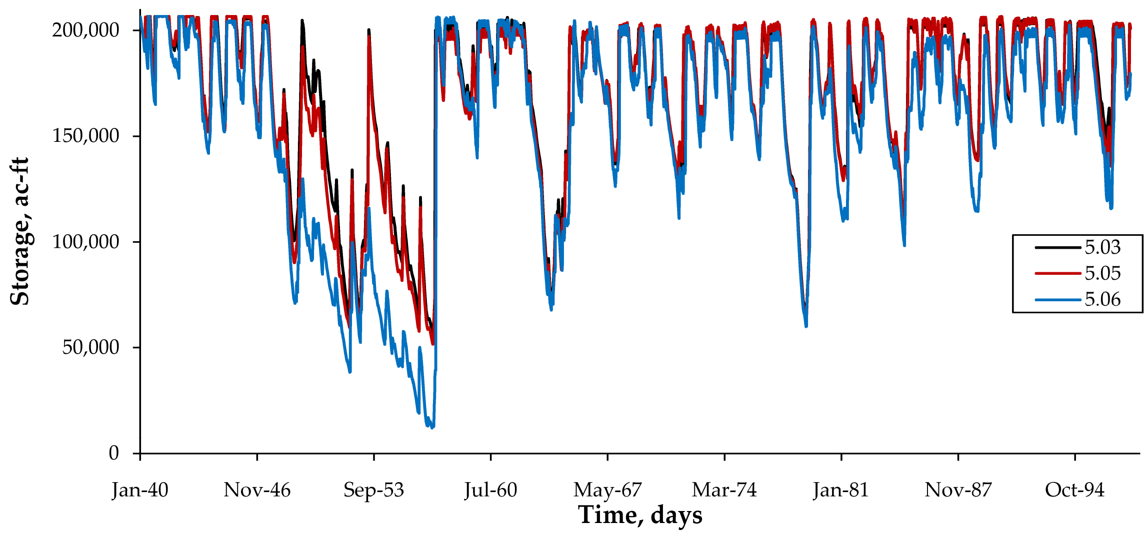

Figure 5.8 Daily Storage in Waco Lake for Scenarios 5.03, 5.05, and 5.06

Daily regulated flow for 1952 at the Bryan gage is shown in Figure 5.9. Regulated flows are those flows that remain at the end of the time step after all water rights have been simulated. Regulated flows are representative of the flow that would physically remain in the stream after all water rights have an opportunity to make diversions and returns.

Like the naturalized flow at the Bryan gage as shown in Figure 5.6, the regulated flow sequences have large differences in flows between the uniform and linear interpolation methods and the flow pattern method as a function of intra-month flow variability. Regulated flows in Figure 5.9 for scenario 5.06 tend to abruptly move toward zero and rebound. Scenario 5.06 is conducted with flow pattern disaggregation but without routing parameters.

Without routing parameters, changes to flow are able to travel from the top of the basin to the outlet, regardless of distance, at the moment the changes are made each day. Mismatches will exist between the speed at which the changes to flow can travel to the outlet and the speed at which the flow event waves are propagating downstream. The flow pattern method of disaggregation uses real-world flows that have travel time embedded in their hydrographs. Therefore, routing parameters should always be used when using the flow pattern method of disaggregation so changes to flow can track downstream at the same rate as the underlying flow event that produced the upstream water availability.

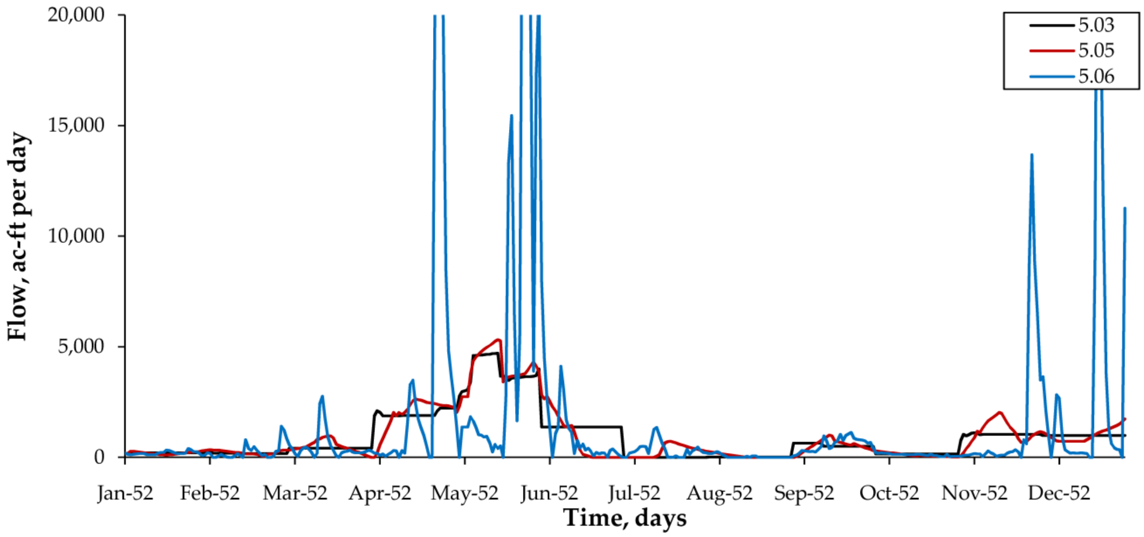

Figure 5.9 Daily Regulated Flows at the Bryan Gage for 1952

Figure 5.10 shows daily naturalized flow at the location of Whitney Lake and the Bryan and Richmond streamflow gages as disaggregated by the flow pattern method. Travel time between locations is visually apparent in the figure in the form of the lag in the arrival time of the flow events in an upstream to downstream manner. The locations of these gages are shown in Figure 4.1, and the control point identifiers are listed in Table 4.1. The hydrograph at Whitney tends to peak two or three days before the hydrograph at Bryan. The hydrograph at Bryan tends to peak two or three days before the hydrograph at Richmond. The routing parameters calibrated and listed in Table 4.7 capture the average characteristics of time lag and attenuation of flows over the period of record.

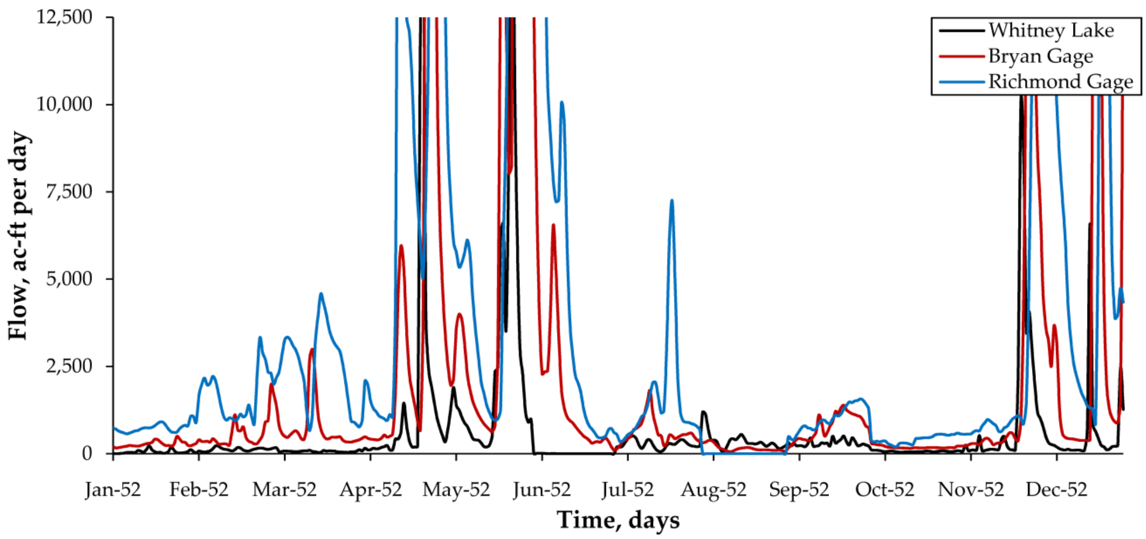

Figure 5.10 Daily Naturalized Flows at the Various Locations for the Flow Pattern Method of Disaggregation

Routing parameters are used in scenario 5.08 along with the flow pattern method of disaggregation. The regulated and unappropriated flow-frequencies for scenarios 5.06 and 5.08 are listed in Tables 5.15 and 5.16. When routing parameters are added to the simulation in conjunction with daily flow pattern disaggregation, there is an increase in the regulated and unappropriated flow at lower magnitude flows. The increase in lower magnitude flows can be seen in Figure 5.11, which plots the regulated flow at the Bryan gage for scenarios 5.06 and 5.08. The addition of routing parameters to the simulation to accompany the flow pattern disaggregation method allows changes to flow to realistically track downstream with the underlying flow events. When routing parameters are used, upstream diversions under higher flow conditions will arrive with the correct temporal phasing to match the corresponding rise in the downstream hydrograph as the flow wave migrates toward the basin outlet.

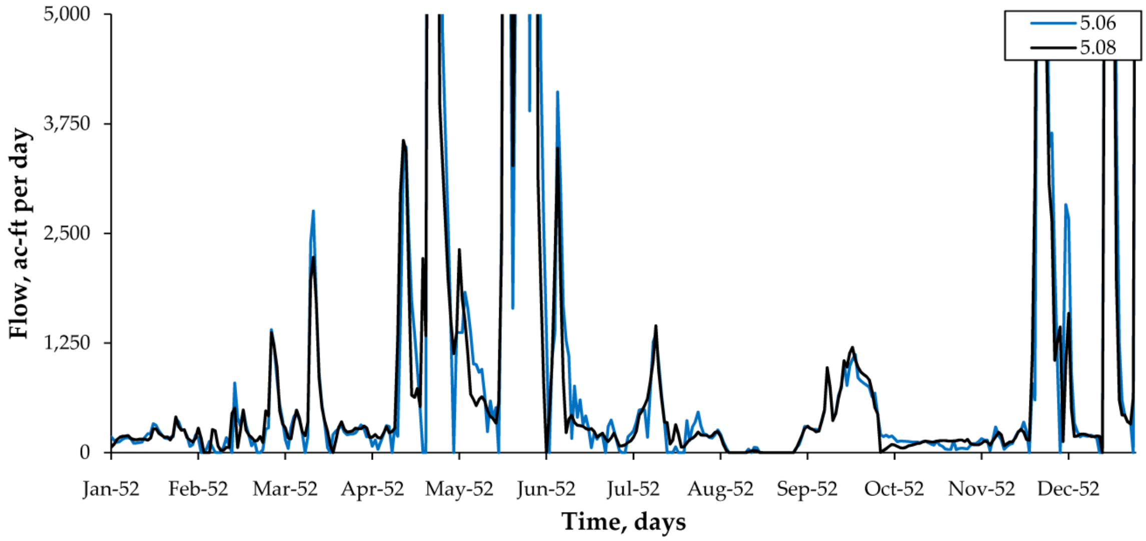

Figure 5.11 Daily Regulated Flows at the Bryan Gage for Scenarios 5.06 and 5.08

Routing parameters are also added to the simulation using the uniform flow disaggregation method. Scenario 5.07 is the identifier of the simulation scenario with uniform flow disaggregation and routing parameters. Intra-month flow events are smoothed by the uniform and linear interpolation disaggregation methods, so there is a mismatch in flow event tracking by allowing changes in flow to move downstream through every control point to the outlet of the basin at the moment the change to flow is made.

Figure 5.12 shows regulated flow at the Bryan gage for the uniform flow disaggregation scenarios with and without routing parameters. There is a peak upward in regulated flow at the beginning of months where the uniformly disaggregated daily naturalized flow increases over the previous month's amount. Regulated flows decrease at the beginning of the month where the uniformly disaggregated daily naturalized flows are below the previous month's amount. At the beginning of each month, new daily target demand amounts are established for the entire month. The changes to flow made by upstream water rights to meet their respective daily target demands require time to propagate downstream and reduce regulated flow when routing parameters are used in the simulation. Once the changes to flow propagate downstream, the upstream water rights' water availability is reduced and streamflow depletions are reduced. This causes a reversal of the regulated flow in Figure 5.12 for scenario 5.07 after the beginning of the month. The regulated flow hydrograph for scenario 5.07 reaches a plateau toward the middle of the month as water rights and their accumulating downstream depletions reach a steady state.

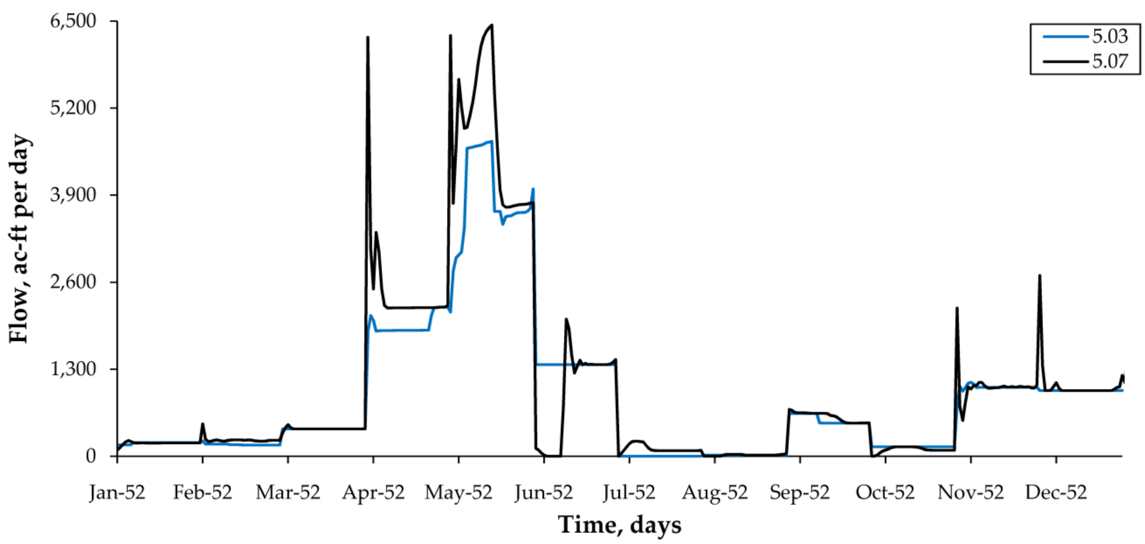

Figure 5.12 Daily Regulated Flows at the Bryan Gage for Scenarios 5.03 and 5.07

Regulated flow at the Bryan gage for the uniform and linear interpolation disaggregation scenarios without routing are compared to the flow pattern disaggregation scenario with routing in Figures 5.13 and 5.14. The figures cover the same period of time but with a different scale on the ordinate axis of Figure 5.14 to make the lower flow magnitudes visible. A high flow event passes through the Bryan gage between May and July 1987. Substantial differences in regulated flow variability are visible due to the selected method of naturalized flow disaggregation.

Figures 5.15 and 5.16 show the daily storages in Belton and Waco Lakes, respectively, for simulations using the uniform and flow pattern methods of disaggregation and with and without the use of routing parameters. The figures show daily storages from January 1940 through September 1965 to highlight the drought of the 1950s, where the greatest differences in storage with respect to disaggregation method occur. Scenarios 5.03 and 5.07 use the uniform distribution method of disaggregation. Scenarios 5.06 and 5.08 use the flow pattern method of disaggregation. Scenarios 5.07 and 5.08 use routing parameters, unlike scenarios 5.03 and 5.06. The drought period storages rise when routing parameters are added to the simulation scenario with flow pattern disaggregation. The rise in storage is attributable to improved water availability as a result of improved timing between the cascade of streamflow depletions from upstream to downstream reaches and the arrival of the underlying flow events in the flow patterns at the downstream locations. However, large differences remain between the scenarios using the flow pattern method of disaggregation and those using the uniform or linear interpolation methods.

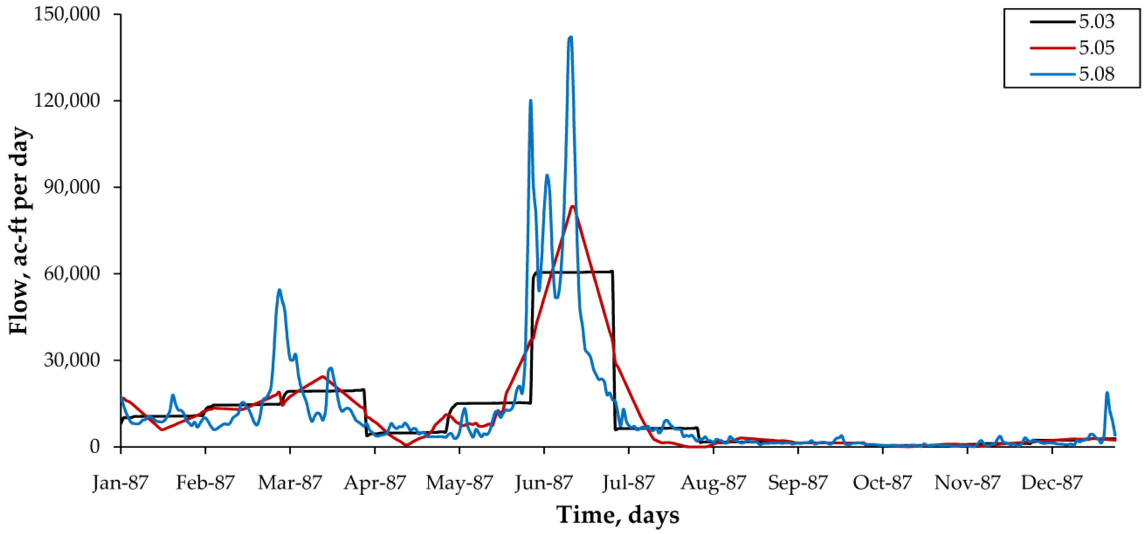

Figure 5.13 Daily Regulated Flows at the Bryan Gage for 1987

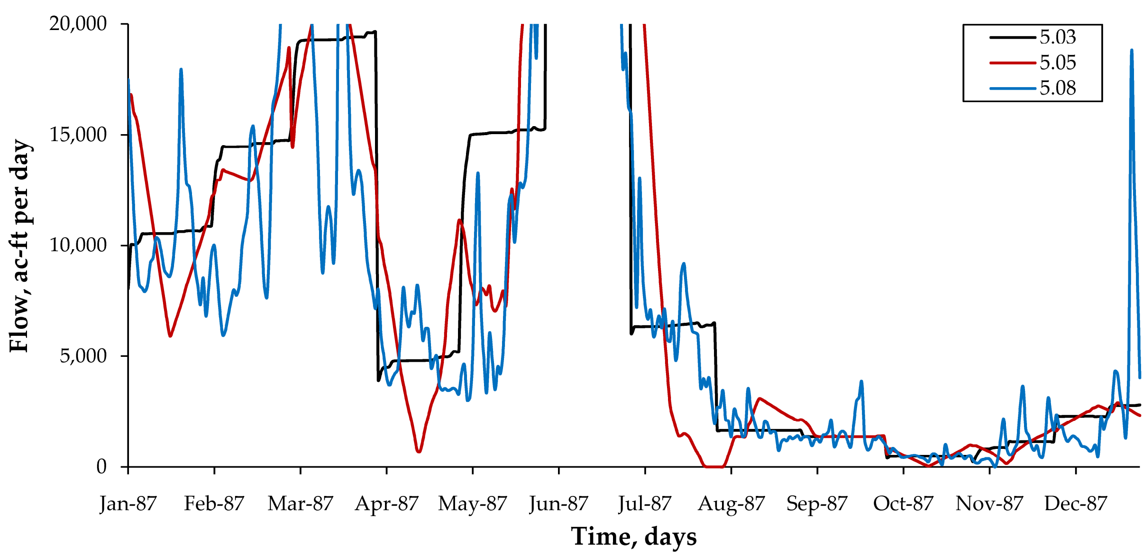

Figure 5.14 Lower Range of Daily Regulated Flows at the Bryan Gage for 1987

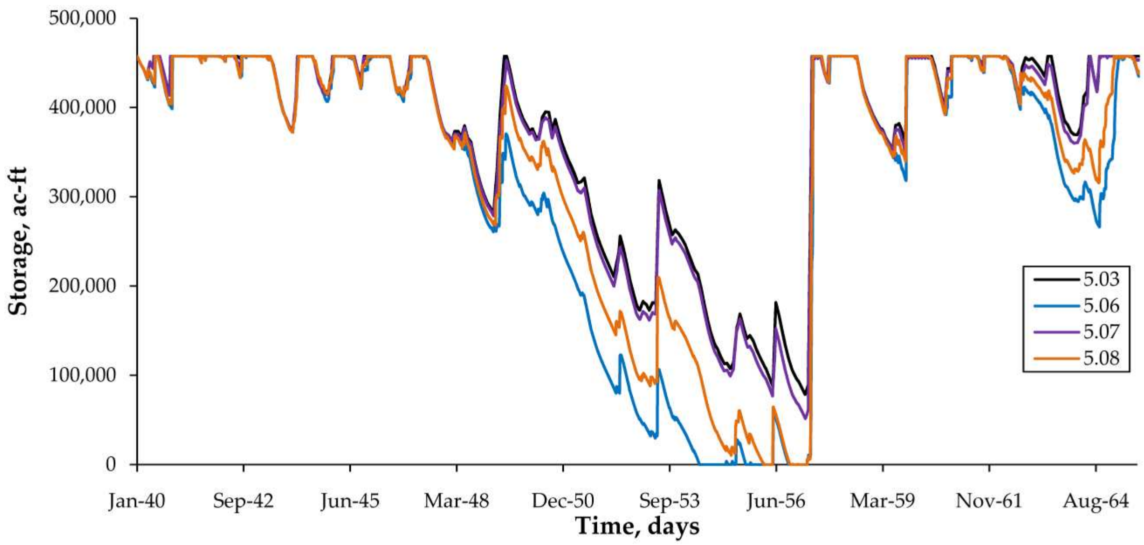

Figure 5.15 Daily Storage in Belton Lake for 1940 through 1965

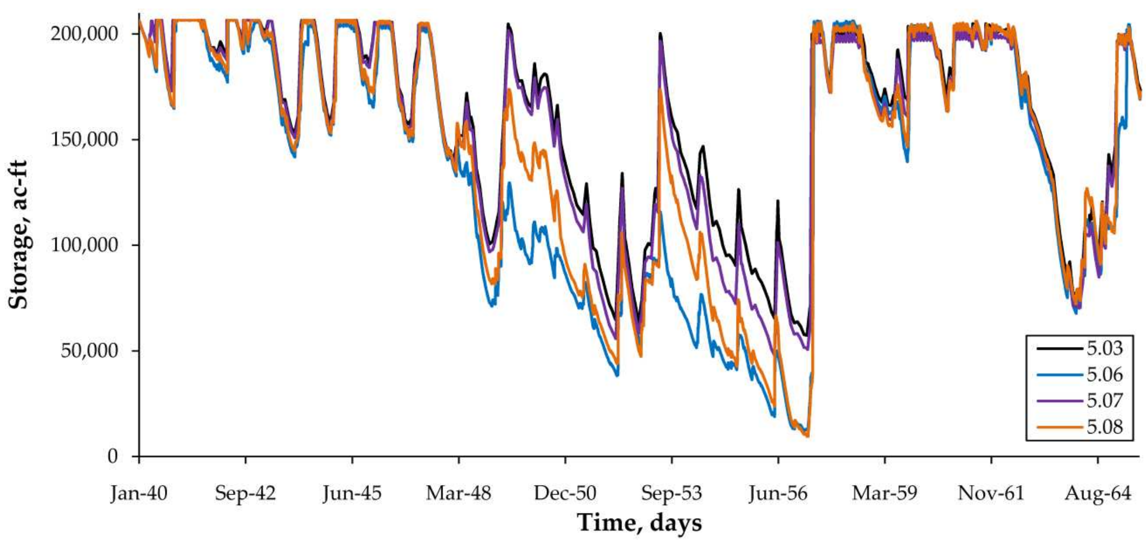

Figure 5.16 Daily Storage in Waco Lake for 1940 through 1965

Daily naturalized, regulated, and unappropriated flows for scenario 5.08 are shown in Figures 5.17 and 5.18 at the Bryan gage for 1952 and 1987, respectively. The two years differ hydrologically, with 1952 being characterized by severe drought and 1987 containing a large high flow event. Daily unappropriated flow at Bryan is nearly zero throughout much of 1952 as upstream water rights make depletions to meet target demands and to refill storage. Some unappropriated flow exists in the high flow events of 1952 when flow increases rapidly. Upstream water rights are not able to fully capture all water contained in pulse flow events. Naturalized flow variability from the flow pattern method of disaggregation ultimately reduces simulated water right efficiency in capturing streamflow to meet target demands throughout the month. Intra-month daily flow variability leads to increased likelihood of simulated water right shortages before and after the pulse flow event.

Unappropriated flow at the Bryan gage is compared between scenarios using the uniform, linear interpolation, and flow pattern methods of disaggregation in Figures 5.19 and 5.20. Unappropriated flow is zero throughout 1952 for the scenarios using the uniform and linear interpolation methods of disaggregation. Because pulse flow events are smoothed across the entire month in the uniform and linear interpolation methods, water rights can apply their target demands against these events throughout the month. In reality, these short duration flow pulses occur over sub-monthly time scales. The uniform and linear interpolation methods artificially increase water availability to water rights, and subsequently unappropriated flow is reflective of increased levels of water right streamflow depletion.

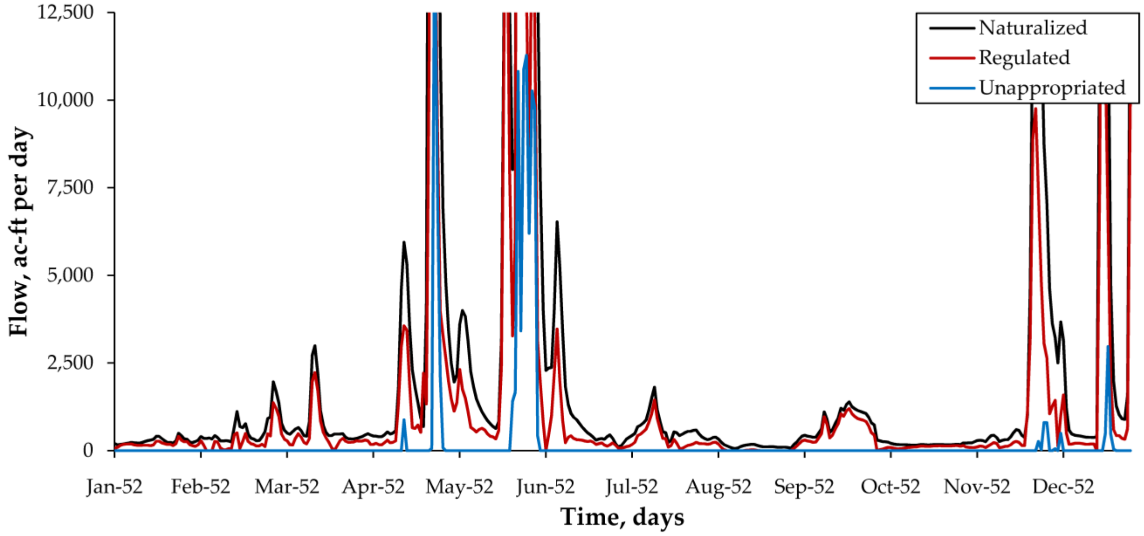

Figure 5.17 Daily Naturalized, Regulated, and Unappropriated Flows for 1952 at the Bryan Gage for Scenario 5.08

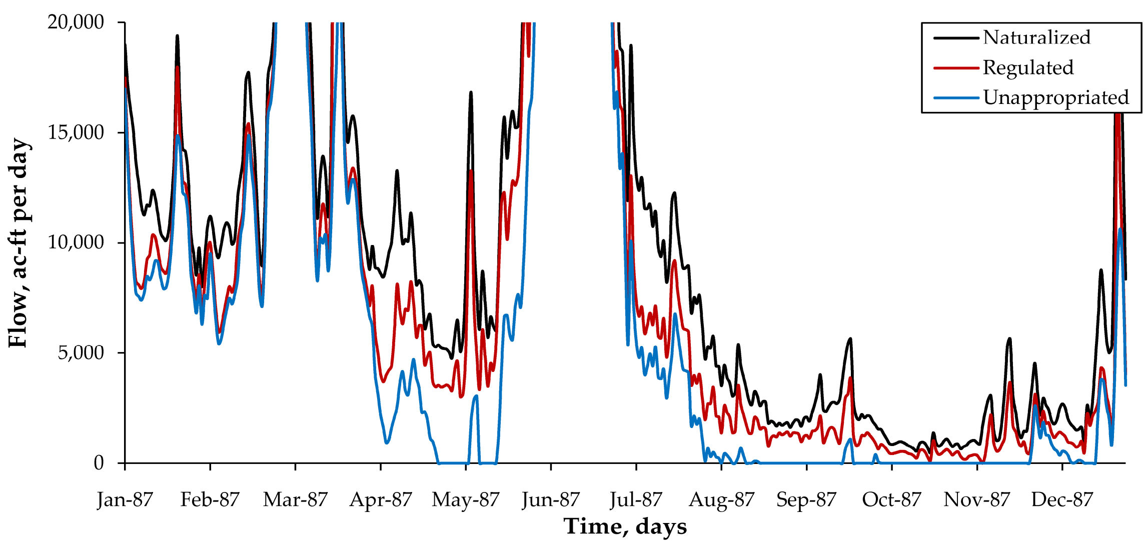

Figure 5.18 Daily Naturalized, Regulated, and Unappropriated Flows for 1987 at the Bryan Gage for Scenario 5.08

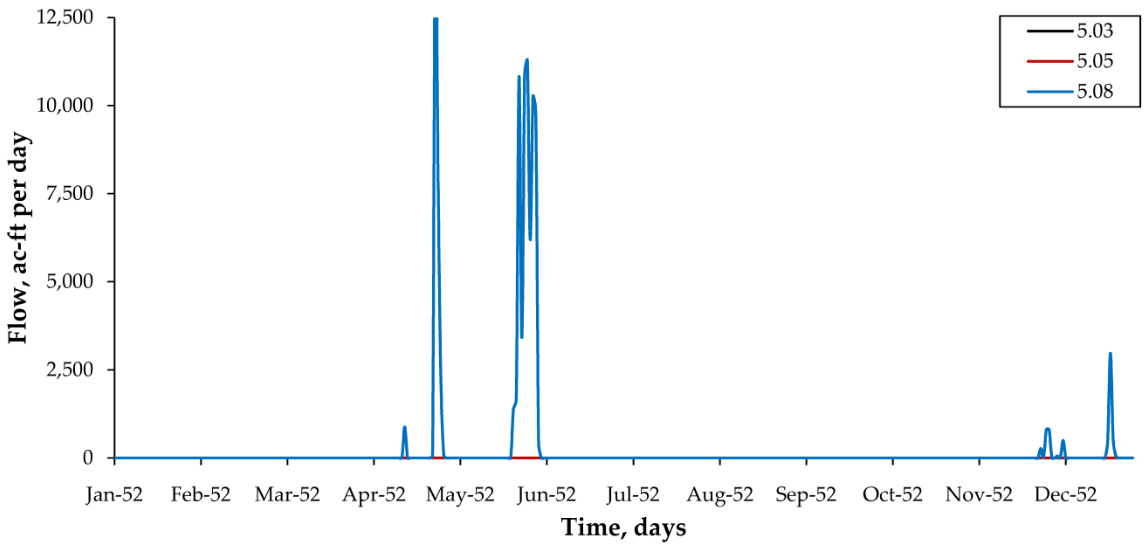

Figure 5.19 Daily Unappropriated Flows for 1952 at the Bryan Gage for Scenarios 5.03, 5.05, and 5.08

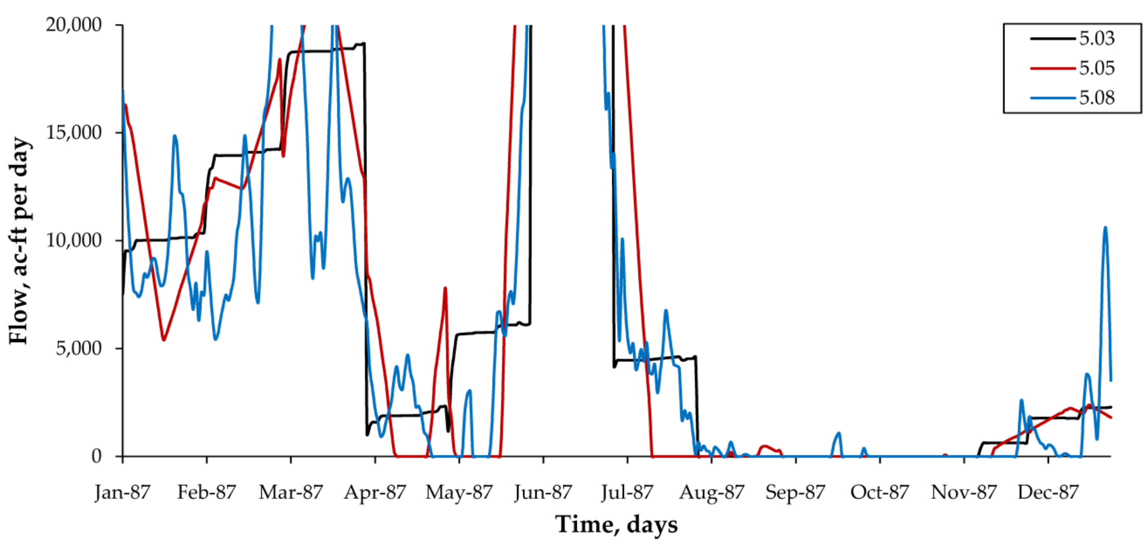

Figure 5.20 Daily Unappropriated Flows for 1987 at the Bryan Gage for Scenarios 5.03, 5.05, and 5.08

Reliability for water rights at the control point locations of the BRA reservoirs are shown in Table 5.17 with respect to the different disaggregation methods. The reservoir names are listed along with the control point identifiers in Table 4.1. Reservoir storage frequency is higher with the uniform and linear interpolation disaggregation methods. Consequently, volume reliability is slightly higher in these scenarios than in the scenarios utilizing the flow pattern disaggregation method. Reservoir storage is non-zero through the majority of the simulation. Non-zero reservoir storage leads to insensitivity of reliabilities at these locations with respect to the methods of disaggregation. Water rights without access to reservoir storage as a backup source of water, however, are expected to exhibit greater sensitivity to streamflow variability caused by the choice of disaggregation method. The addition of routing in scenario 5.08 improves water availability with the flow pattern method of disaggregation. Reservoir storage improves in scenario 5.08 over scenario 5.06.

Mean annual shortage and volume reliability for selected run-of-river water rights are shown in Tables 5.18 and 5.19, respectively. The number and total annual targets of these water right groupings are given in Table 5.2. These water right groupings do not include any water rights with access to reservoir storage as a backup source of water. Consequently, there is an overall greater sensitivity of reliability to the choice of disaggregation method by these water rights than was illustrated by the water rights with storage access as shown in Table 5.17.

Table 5.17 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.03, 5.05, 5.06, and 5.08

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
					Scenario 5.03, Uniform Disaggregation						
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							
					Scenario 5.05, Linear Interpolation Disaggregation						
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18736.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	19.31	99.57	99.86	99.6	99.6	99.6	99.7	99.9	100.0	100.0
509431	98005.0	2684.29	92.39	97.26	92.4	92.5	92.8	94.0	99.4	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	680.96	97.56	99.00	97.6	97.7	97.8	98.1	99.1	99.4	99.4
516231	13610.0	326.03	96.84	97.60	96.8	96.8	96.8	97.1	97.4	97.7	98.1
516331	19840.0	168.25	98.71	99.15	98.7	98.7	98.7	98.9	99.3	99.3	99.3
516431	48000.0	90.10	99.43	99.81	99.4	99.6	99.6	99.7	99.7	99.7	99.9
Total	772306.9	3968.96		99.49							

Table 5.17 Continued

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
Scenario 5.06, Flow Pattern Disaggregation without Routing											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18736.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	1043.48	91.38	92.49	91.4	91.4	91.5	91.7	92.0	93.1	94.5
509431	99067.2	5431.95	85.92	94.52	85.9	86.1	86.2	87.5	97.8	99.4	100.0
516531	65074.0	1420.22	96.98	97.82	97.0	97.0	97.0	97.3	97.4	97.8	98.9
515931	19658.0	1121.30	93.10	94.30	93.1	93.1	93.1	93.2	93.7	94.1	96.1
516031	112257.0	3498.24	95.83	96.88	95.8	96.0	96.0	96.1	96.4	97.3	97.6
516131	67768.0	6185.29	89.80	90.87	89.8	89.8	89.8	89.8	90.4	91.4	94.5
516231	13610.0	1282.78	89.51	90.57	89.5	89.7	89.7	90.1	90.2	90.8	93.2
516331	19840.0	1141.34	92.96	94.25	93.0	93.1	93.1	93.4	93.5	94.5	95.8
516431	48000.0	760.22	97.70	98.42	97.7	97.7	97.8	97.8	98.0	98.4	99.7
Total	773369.0	21884.86		97.17							
Scenario 5.08, Flow Pattern Disaggregation with Routing											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							

Table 5.18 Mean Shortage for Selected Run-of-river Water Rights for Scenarios 5.03, 5.05, 5.06, and 5.08

Selected Water Rights	Target Diversion ac-ft per year	Mean Annual Shortage, ac-ft per year			
		5.03	5.05	5.06	5.08
Dec. 31, 1929, and Senior, all uses	120,722	2,287	5,244	5,064	10,090
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	2,033	4,986	7,848	8,020
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	15,256	23,283	34,511	36,433
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	13,567	19,201	26,297	25,967
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	20,385	25,213	34,801	34,174
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,157	1,345	1,696	1,462
Jan. 1, 1980, and Junior, municipal use	75,000	10,460	14,307	20,816	16,109
Jan. 1, 1980, and Junior, non-municipal use	84,261	27,047	30,203	37,323	32,912
All Selected Water Rights	790,221	92,191	123,781	168,356	165,165

Table 5.19 Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.03, 5.05, 5.06, and 5.08

Selected Water Rights	Volume Reliability, %			
	5.03	5.05	5.06	5.08
Dec. 31, 1929, and Senior, all uses	98.1	95.7	95.8	91.6
Jan. 1, 1930, to Dec. 31, 1939, all uses	97.3	93.4	89.6	89.4
Jan. 1, 1940, to Dec. 31, 1949, all uses	92.1	87.9	82.0	81.0
Jan. 1, 1950, to Dec. 31, 1959, all uses	87.9	82.9	76.6	76.9
Jan. 1, 1960, to Dec. 31, 1969, all uses	83.8	80.0	72.3	72.8
Jan. 1, 1970, to Dec. 31, 1979, all uses	75.3	71.3	63.8	68.9
Jan. 1, 1980, and Junior, municipal use	86.1	80.9	72.2	78.5
Jan. 1, 1980, and Junior, non-municipal use	67.9	64.2	55.7	60.9
All Selected Water Rights	88.3	84.3	78.7	79.1

5.4 Placement of Routed Changes to Flow

This section examines the effect of the choice of placement of routed changes to flow. Changes to flow from WR record water rights in prior time steps can be routed downstream at the beginning of the priority sequence or within the priority sequence at the priority order of the water right that made the change to flow. Changes to flow from previous days can be routed at the beginning of each daily time step using JU record option WRMETH 1. This allows the previous changes to flow to affect water availability for all water rights in the basin until the changes to flow exit the basin's outlet. The alternative option, WRMETH 2, is used to route the changes to flow at the priority order in which the original depletion was made. Only the water right making the depletion and all junior water rights will experience a direct impact to water availability as the changes to flow travel to the outlet.

Over-appropriation can occur when upstream depletions in past days are routed downstream at a different rate than the underlying flow event from which they were taken. The primary cause is a mismatch in the rate of propagation of the flow event and the rate of travel of the flow depletion according to the routing parameters. WRMETH 2 also allows for over-appropriation when senior rights make streamflow depletions of water that was appropriated by upstream juniors in previous days. Forecasting for water availability is applied as a tool in this section to minimize water balance makeup as a result of over-appropriation.

Four simulation scenarios are considered in this section. The scenario identifiers are given in Table 5.20. All of the scenarios use routing parameters and the flow pattern method of disaggregation to obtain daily naturalized flows.

The four scenarios test the effect of WRMETH 1 and WRMETH 2 with and without the use of forecasting.

Table 5.20 Parameters per Simulation Scenario in Section 5.4

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na
5.09	day	Bwam3	lag-att	2	daily pattern	uniform	0 days	na
5.11	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	1
5.12	day	Bwam3	lag-att	2	daily pattern	uniform	3 days	6

Tables 5.21 through 5.25 present simulation results for scenarios 5.08 and 5.09. The tables of simulation results consist of the following:

- Table 5.21: End-of-Day Storage Frequency
- Table 5.22: Flow Frequency of Daily Regulated Flow
- Table 5.23: Flow Frequency of Daily Unappropriated Flow
- Table 5.24: Reliability Summaries for BRA Reservoir Water Rights
- Table 5.25: Shortage and Volume Reliability for Selected Run-of-River Water Rights

Storage and flow-frequencies are slightly different between the two methods of placing routed changes to flow. The slight change in storage frequency is accompanied by only a slight change in the control point reliability summary for water rights with access to the reservoirs. The run-of-river rights exhibit sensitivity in reliability to the choice of WRMETH. In particular, water rights with priorities less than or equal to 1969 show the most difference between the scenario using WRMETH 1 and the scenario using WRMETH 2. Layering routed changes to flow within the priority sequence via WRMETH 2 shields these senior rights from the routed changes to flow connected with water rights junior to 1969.

Table 5.21 End-of-day Storage Frequency for Scenarios 5.08 and 5.09, ac-ft

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
			100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
					Scenario 5.08, WRMETH 1						
515531	633117.	97579.	218468.	373546.	450143.	490128.	578876.	664988.	713850.	724541.	724739.
515631	133553.	26008.	36596.	57263.	72475.	97595.	121399.	143696.	154188.	155000.	155000.
515731	591271.	54946.	365112.	407255.	451365.	522237.	577696.	607028.	630332.	635745.	636100.
515831	41000.	11930.	0.	4316.	15564.	23926.	36055.	44638.	50164.	52071.	52400.
509431	158176.	47017.	8510.	38143.	57646.	80479.	135835.	172650.	195978.	201864.	206562.
516531	174609.	54500.	0.	20496.	47519.	90952.	151423.	191492.	218206.	222733.	225400.
515931	42500.	15823.	0.	3615.	7849.	18640.	33596.	44865.	56954.	59393.	59400.
516031	375705.	110735.	0.	17977.	94813.	212970.	355511.	416125.	452731.	457600.	457600.
516131	181743.	69537.	0.	0.	364.	37235.	165258.	209298.	231372.	235700.	235700.
516231	27344.	11111.	0.	0.	295.	9092.	20775.	31971.	36043.	37100.	37100.
516331	53377.	17266.	0.	1033.	11007.	27158.	48319.	61971.	65500.	65500.	65500.
516431	129898.	36067.	0.	30227.	55981.	71225.	113618.	142781.	159740.	160110.	160110.
Total	2542291.	479728.	957754.	1121952.	1442010.	1775366.	2367310.	2691557.	2900170.	2981422.	3015611.
					Scenario 5.09, WRMETH 2						
515531	646784.	89028.	230529.	396472.	486214.	524367.	600645.	678219.	718819.	724739.	724739.
515631	133409.	26480.	43917.	55599.	71460.	96437.	121074.	143915.	154531.	155000.	155000.
515731	592396.	54024.	358228.	400938.	466820.	526183.	577922.	607562.	630795.	636055.	636100.
515831	41584.	12386.	0.	2607.	13385.	24440.	36710.	45355.	51558.	52400.	52400.
509431	159081.	45336.	13666.	43780.	61950.	83427.	137629.	172729.	195548.	201559.	206562.
516531	175312.	54616.	0.	19871.	46959.	92289.	152856.	192204.	218879.	223876.	225400.
515931	44238.	15361.	0.	4860.	11439.	20333.	36363.	47146.	58777.	59400.	59400.
516031	384206.	103171.	0.	50325.	125348.	235295.	366337.	422582.	457133.	457600.	457600.
516131	184219.	68851.	0.	0.	4120.	46979.	169444.	212418.	234102.	235700.	235700.
516231	27878.	11181.	0.	0.	205.	9143.	21710.	32661.	36965.	37100.	37100.
516331	53014.	17689.	0.	103.	8990.	25941.	48170.	61586.	65500.	65500.	65500.
516431	129822.	36276.	0.	28646.	55978.	71044.	113463.	142956.	159750.	160110.	160110.
Total	2571944.	456992.	1056013.	1204905.	1538719.	1823739.	2415942.	2717744.	2919236.	2990233.	3015611.

Table 5.22 Flow Frequency of Daily Regulated Flow for Scenarios 5.08 and 5.09, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
						Scenario 5.08, WRMETH 1					
LRCA58	2756.22	8622.7	0.00	0.00	21.60	39.67	97.50	408.5	1864.7	6382.4	289130.7
BRBR59	8117.65	21589.2	0.00	0.00	98.88	219.76	575.50	1567.5	5858.2	20097.7	711444.9
BRHE68	11303.78	24501.7	0.00	144.52	310.77	514.66	1119.50	2716.4	10410.9	30664.7	750731.2
BRRI70	12313.41	25160.6	0.00	71.48	319.61	605.03	1397.62	2912.4	11854.8	33347.7	636331.9
BRGM73	11436.87	25868.9	0.00	0.00	0.00	0.00	0.00	1498.6	10873.6	32857.3	575855.3
515531	1156.11	5873.9	0.00	0.00	0.00	0.00	0.00	0.0	203.5	1647.5	155382.6
515631	1689.04	7322.5	0.00	0.00	0.00	0.00	0.00	47.2	547.3	2815.6	157099.3
515731	2196.45	8216.3	0.00	0.00	0.00	0.00	11.25	211.4	1014.6	4054.9	187870.6
515831	146.89	1072.5	0.00	0.96	0.99	0.99	0.99	1.0	4.4	96.5	37727.5
509431	648.06	3482.3	0.00	0.00	0.00	0.00	0.00	0.0	133.9	1138.2	219400.2
516531	379.20	2032.5	0.00	0.00	0.00	0.00	0.00	0.0	34.6	370.2	72120.4
515931	284.75	2151.7	0.00	0.00	0.00	0.00	0.00	1.6	51.6	401.5	197850.8
516031	930.19	3743.5	0.00	0.00	0.00	0.00	0.00	25.3	359.8	2130.1	164586.3
516131	416.10	2082.5	0.00	0.00	0.00	0.00	0.00	13.2	128.6	1023.5	120488.7
516231	116.87	570.8	0.00	0.00	0.00	0.00	0.00	3.2	50.6	270.0	23854.5
516331	396.02	1541.3	0.00	0.00	0.00	0.00	0.91	35.6	262.1	891.2	60136.2
516431	436.31	2166.2	0.00	0.00	0.00	0.00	0.00	0.0	15.9	677.4	98089.0
						Scenario 5.09, WRMETH 2					
LRCA58	2750.26	8613.2	0.00	0.00	8.19	31.96	92.24	400.2	1844.5	6433.7	288764.8
BRBR59	8092.62	21673.0	0.00	0.00	83.67	205.85	544.90	1479.2	5818.7	20066.9	711287.9
BRHE68	11289.59	24593.7	0.00	94.43	283.15	487.83	1079.03	2653.4	10400.7	30715.9	750097.8
BRRI70	12305.12	25253.4	0.00	14.21	284.73	574.73	1363.16	2842.3	11852.2	33411.7	636006.1
BRGM73	11432.85	25957.1	0.00	0.00	0.00	0.00	0.00	1442.8	10839.8	32871.1	575383.5
515531	1139.23	5903.8	0.00	0.00	0.00	0.00	0.00	0.0	146.7	1582.0	159933.2
515631	1679.88	7389.3	0.00	0.00	0.00	0.00	0.00	42.6	498.3	2683.6	157132.2
515731	2186.18	8274.3	0.00	0.00	0.00	0.00	7.24	192.7	947.5	3986.2	187828.0
515831	146.82	1072.2	0.00	0.96	0.99	0.99	0.99	1.0	4.7	88.5	37727.5
509431	649.35	3488.3	0.00	0.00	0.00	0.00	0.00	0.0	128.0	1154.9	219391.4
516531	378.96	2037.3	0.00	0.00	0.00	0.00	0.00	0.0	29.2	368.2	72225.5
515931	282.72	2157.5	0.00	0.00	0.00	0.00	0.00	2.0	46.0	396.7	197716.7
516031	927.93	3769.3	0.00	0.00	0.00	0.00	0.00	27.9	341.4	2097.5	164959.9
516131	414.11	2061.8	0.00	0.00	0.00	0.00	0.00	14.7	138.7	1001.3	120485.1
516231	116.87	572.3	0.00	0.00	0.00	0.00	0.00	3.7	52.9	266.5	23854.5
516331	396.44	1536.1	0.00	0.00	0.00	0.00	1.92	40.6	258.8	889.1	59486.0
516431	436.45	2167.2	0.00	0.00	0.00	0.00	0.00	0.0	16.7	678.6	98091.0

Note: the percentage columns (100% through 10%) are headed "% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE".

Table 5.23 Flow Frequency of Daily Unappropriated Flow for Scenarios 5.08 and 5.09, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
						Scenario 5.08, WRMETH 1					
LRCA58	1823.96	6238.4	0.00	0.00	0.00	0.00	0.00	0.0	701.3	4820.8	177166.4
BRBR59	5072.60	15405.9	0.00	0.00	0.00	0.00	0.00	0.0	2837.7	13739.9	494806.2
BRHE68	7708.37	20419.8	0.00	0.00	0.00	0.00	0.00	0.0	5128.4	23450.9	484958.7
BRRI70	9416.94	23535.1	0.00	0.00	0.00	0.00	0.00	83.6	7689.8	28072.0	585699.9
BRGM73	11436.87	25868.9	0.00	0.00	0.00	0.00	0.00	1498.6	10873.6	32857.3	575855.3
515531	496.39	3380.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	13.8	88264.9
515631	941.66	5090.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1221.6	136725.1
515731	1307.64	6031.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2364.4	139327.5
515831	94.15	730.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	55.4	23145.8
509431	444.18	2164.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	832.0	66844.3
516531	158.96	815.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	72.2	29750.2
515931	113.58	736.3	0.00	0.00	0.00	0.00	0.00	0.0	0.0	59.3	27416.1
516031	665.55	2658.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1604.9	73944.9
516131	283.41	1245.5	0.00	0.00	0.00	0.00	0.00	0.0	0.0	787.5	72658.6
516231	92.05	436.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	246.3	15600.2
516331	298.98	1209.5	0.00	0.00	0.00	0.00	0.00	0.0	61.1	788.6	43911.1
516431	399.55	1938.1	0.00	0.00	0.00	0.00	0.00	0.0	0.0	607.6	59209.9
						Scenario 5.09, WRMETH 2					
LRCA58	1833.35	6270.3	0.00	0.00	0.00	0.00	0.00	0.0	707.3	4811.9	177142.4
BRBR59	5082.44	15504.4	0.00	0.00	0.00	0.00	0.00	0.0	2807.5	13707.7	494074.7
BRHE68	7717.73	20498.1	0.00	0.00	0.00	0.00	0.00	0.0	5101.6	23458.9	484976.2
BRRI70	9427.40	23622.0	0.00	0.00	0.00	0.00	0.00	38.0	7701.7	28136.6	585216.9
BRGM73	11432.85	25957.1	0.00	0.00	0.00	0.00	0.00	1442.8	10839.8	32871.1	575383.5
515531	513.62	3451.7	0.00	0.00	0.00	0.00	0.00	0.0	0.0	80.2	99112.0
515631	956.42	5173.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1262.3	145920.0
515731	1320.48	6119.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2349.6	142029.2
515831	94.04	734.4	0.00	0.00	0.00	0.00	0.00	0.0	0.0	45.9	25136.7
509431	447.84	2176.5	0.00	0.00	0.00	0.00	0.00	0.0	0.0	853.9	67492.3
516531	160.40	819.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	66.7	28448.6
515931	118.16	755.6	0.00	0.00	0.00	0.00	0.00	0.0	0.0	64.7	27420.0
516031	680.45	2706.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1640.9	74458.1
516131	286.29	1247.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	784.2	73198.2
516231	91.93	434.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	241.4	15024.3
516331	298.03	1208.4	0.00	0.00	0.00	0.00	0.00	0.0	45.6	789.5	43883.9
516431	399.36	1939.2	0.00	0.00	0.00	0.00	0.00	0.0	0.0	608.2	59209.8

Table 5.24 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.08 and 5.09

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
				Scenario 5.08, WRMETH 1							
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							
				Scenario 5.09, WRMETH 2							
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18397.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	207.40	98.42	98.51	98.4	98.4	98.4	98.4	98.4	98.7	99.1
509431	98147.0	3926.39	90.37	96.00	90.4	90.5	90.8	91.7	98.9	99.9	100.0
516531	65074.0	512.81	98.85	99.21	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	95.03	99.57	99.52	99.6	99.6	99.6	99.7	99.7	99.7	99.9
516031	112257.0	171.94	99.71	99.85	99.7	99.7	99.7	99.7	99.7	99.9	100.0
516131	67768.0	2527.47	95.26	96.27	95.3	95.3	95.3	95.5	96.0	96.8	98.0
516231	13610.0	601.50	94.25	95.58	94.3	94.4	94.5	94.8	95.1	96.1	97.7
516331	19840.0	356.50	97.56	98.20	97.6	97.7	97.7	97.8	97.8	98.4	98.9
516431	48000.0	228.02	98.99	99.52	99.0	99.0	99.0	99.0	99.0	99.4	99.9
Total	772109.9	8627.09		98.88							

Table 5.25 Mean Shortage and Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.08 and 5.09

Selected Water Rights	Target Diversion, ac-ft per year	Mean Shortage, ac-ft per year		Volume Reliability, %	
		5.08	5.09	5.08	5.09
Dec. 31, 1929, and Senior, all uses	120,722	10,090	5,730	91.6	95.3
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	8,020	5,489	89.4	92.7
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	36,433	30,810	81.0	84.0
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	25,967	22,661	76.9	79.8
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	34,174	31,036	72.8	75.3
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,462	1,494	68.9	68.2
Jan. 1, 1980, and Junior, municipal use	75,000	16,109	16,301	78.5	78.3
Jan. 1, 1980, and Junior, non-municipal use	84,261	32,912	33,606	60.9	60.1
All Selected Water Rights	790,221	165,165	147,127	79.1	81.4

Table 5.26 shows the aggregated monthly amount of makeup for scenarios 5.08 and 5.09 for all time steps in the 58-year period of record from 1940 to 1997. Daily makeup amounts are carried forward to subsequent time steps until the water balance of the streamflow availability array returns to zero or to a positive value. WRMETH 2 results in greater violations of the water. The total amount of makeup is also presented as a percentage of the total naturalized flow for the period of record. Water balance makeup is more likely when the regulated flows are low. The 29 years with the lowest naturalized flow at each control point are selected from the period of record. Water balance makeup during these lowest flow years are reported separately in Table 5.26.

Table 5.26 Water Balance Makeup at Selected Control Points for Scenarios 5.08 and 5.09

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.08, WRMETH 1			
BRBR59	Bryan Gage	-1,190.6	-0.030	-2,356.5	-0.113
BRHE68	Hempstead Gage	-1,608.0	-0.030	-3,157.2	-0.111
BRRI70	Richmond Gage	-1,496.7	-0.026	-2,801.0	-0.089
LRCA58	Cameron Gage	-46.1	-0.003	-92.2	-0.017
BRGM73	Gulf Outlet	-691.7	-0.011	-1,233.0	-0.038
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-837.9	-0.077	-1,136.2	-0.195
515731	Whitney Lake	-544.6	-0.040	-368.3	-0.049
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.6	0.000	-0.3	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-50.6	-0.010	-99.6	-0.052
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.4	0.000	-0.8	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.09, WRMETH 2			
BRBR59	Bryan Gage	-4,476.1	-0.111	-8,797.8	-0.423
BRHE68	Hempstead Gage	-6,808.7	-0.127	-12,814.0	-0.449
BRRI70	Richmond Gage	-6,934.0	-0.119	-12,648.1	-0.404
LRCA58	Cameron Gage	-213.9	-0.016	-405.6	-0.075
BRGM73	Gulf Outlet	-8,824.3	-0.145	-14,152.1	-0.431
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-4,130.5	-0.378	-5,440.9	-0.935
515731	Whitney Lake	-2,291.0	-0.168	-1,619.5	-0.213
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-782.4	-0.219	-882.8	-0.567
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-132.4	-0.026	-243.0	-0.126
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-5.4	-0.003	-7.8	-0.012
516431	Somerville Lake	0.0	0.000	0.0	0.000

Scenario 5.11 uses WRMETH 1, forecasting method 1, and a forecasting period of 3 days for all water rights. Scenario 5.12 uses WRMETH 2, forecasting method 6, and a forecasting period of 3 days for all water rights. Forecasting method 1 uses the largest daily summation of downstream senior water right shortages during the forecasting period as a metric to reduce water availability to the water right employing forecasting. Forecasting method 6 uses minimum daily computation of downstream water availability during the forecasting period as a metric to reduce water availability to the water right employing forecasting.

Table 5.27 shows the water balance makeup for the scenarios that use forecasting. Less makeup is required after the application of forecast, as compared to the results of Table 5.26. Combining forecast method 6 with WRMETH 2 results in less water balance makeup than for the same number of forecasting days when applying forecasting method 1 with WRMETH 1. Alternative number of days of forecasting and forecasting methods could be explored for individual water rights to find a minimization of the volume of the water balance makeup with WRMETH 1.

Run-of-river water right shortages and reliabilities are presented in Table 5.28 for scenarios 5.11 and 5.12. Compared with the shortages and reliabilities in Table 5.25, the scenarios that use WRMETH 1 show improvement in reliability for senior rights but a slight decrease in reliability for junior rights. Overall shortage and reliability are not substantially changed between scenarios 5.08 and 5.11 by the addition of forecasting. The scenarios using WRMETH 2 show increased reliability in most water right groupings when forecasting is added to the simulation.

Table 5.27 Water Balance Makeup at Selected Control Points for Scenarios 5.11 and 5.12

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.11, WRMETH 1			
BRBR59	Bryan Gage	-871.2	-0.022	-1,742.4	-0.084
BRHE68	Hempstead Gage	-940.6	-0.018	-1,880.8	-0.066
BRRI70	Richmond Gage	-844.7	-0.014	-1,636.4	-0.052
LRCA58	Cameron Gage	-4.3	0.000	-8.6	-0.002
BRGM73	Gulf Outlet	-285.7	-0.005	-544.7	-0.017
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-505.6	-0.046	-705.3	-0.121
515731	Whitney Lake	-423.2	-0.031	-213.2	-0.028
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-1.9	-0.001	-1.7	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-1.2	0.000	-2.2	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-1.2	-0.001	-2.3	-0.004
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.12, WRMETH 2			
BRBR59	Bryan Gage	-55.6	-0.001	-111.2	-0.005
BRHE68	Hempstead Gage	-259.0	-0.005	-518.1	-0.018
BRRI70	Richmond Gage	-342.5	-0.006	-685.1	-0.022
LRCA58	Cameron Gage	-3.7	0.000	-6.8	-0.001
BRGM73	Gulf Outlet	-284.5	-0.005	-455.6	-0.014
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-0.4	0.000	-0.5	0.000
515731	Whitney Lake	-0.8	0.000	-1.2	0.000
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-126.0	-0.035	-97.1	-0.062
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-1.0	0.000	-0.9	0.000
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.2	0.000	-0.1	0.000
516431	Somerville Lake	0.0	0.000	0.0	0.000

Table 5.28 Mean Shortage and Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.11 and 5.12

Selected Water Rights	Target Diversion, ac-ft per year	Mean Shortage, ac-ft per year		Volume Reliability, %	
		5.11	5.12	5.11	5.12
Dec. 31, 1929, and Senior, all uses	120,722	7,212	5,232	94.0	95.7
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	6,018	5,421	92.0	92.8
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	33,020	28,684	82.8	85.1
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	27,522	23,729	75.5	78.9
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	30,991	30,260	75.4	75.9
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,566	1,417	66.6	69.8
Jan. 1, 1980, and Junior, municipal use	75,000	16,927	15,954	77.4	78.7
Jan. 1, 1980, and Junior, non-municipal use	84,261	32,095	33,087	61.9	60.7
All Selected Water Rights	790,221	155,352	143,784	80.3	81.8

The intent of this section is to examine the relative differences between the use of WRMETH 1 and WRMETH 2. Overall, the two methods perform similarly with respect to storage, regulated, and unappropriated flow frequency. Water right reliability is slightly higher with WRMETH 2. The slight advantage in water right reliability of WRMETH 2 versus WRMETH 1 comes at the expense of greater water balance violations when forecasting is not employed during the simulation. Forecasting should always be used with WRMETH 2 to deal with the potential for over-appropriation of streamflow due to the unrealistic segregation of routed junior streamflow depletions from the computation of water availability for senior rights. Conclusions about the effectiveness of forecasting method 1 versus forecasting method 6 should not be drawn from the results of this section. Use of forecasting is shown here only to illustrate a relative reduction in over-appropriation.

5.5 Methods of Forecasting Water Availability

Forecasting can improve water availability for downstream senior rights and can reduce the amount of water balance makeup that occurs due to over-appropriation. Forecasting methods 1, 3, and 5 are examined in this section. These forecasting methods use measurements of future downstream senior shortages as a quantity to reduce present-day water availability. Forecasting method 1 records the maximum of the daily totals of downstream senior shortages over the forecast period. Forecasting method 3 records the maximum shortage of any single downstream senior water right during any day of the forecasting period. Forecasting method 5 cancels water availability to the water right applying forecasting if any downstream senior water right experiences a shortage of any size during any day of the forecast period. Forecasting methods 2 and 4 are analogous to methods 1 and 3, respectively, except that methods 2 and 4 do not increase the measured downstream senior shortage by the amount of channel loss between the upstream right and the downstream senior rights.

Only scenarios using WRMETH 1 are considered in this section. Therefore, only forecasting methods related to future downstream senior shortages are considered. Downstream future water availability is intended for use with WRMETH 2. A forecasting period of 3 days is used in each scenario that applies one of the selected forecasting methods. The identifiers of the scenarios considered in this section are listed in Table 5.29.

Table 5.29 Parameters per Simulation Scenario in Section 5.5

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na
5.11	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	1
5.13	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	3
5.14	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	5

Table 5.30 presents daily storage frequency. As compared with scenario 5.08, the scenarios using forecasting methods 1 and 3 show a slight decrease in the mean reservoir storage content. However, the total mean reservoir storage decreases from 2,542,291 to 1,294,884 ac-ft between scenarios 5.08 and 5.14. The number of zero storage days for the reservoirs is significantly greater with scenario 5.14. Water right reliabilities for the water rights located at the control points of the reservoirs are sensitive to the number of zero storage days for their respective reservoirs.

Tables 5.31, 5.32, and 5.33 present water right reliabilities. As compared with scenario 5.08, the scenarios using forecasting methods 1 and 3 do not show significant changes in reliability. Forecasting method 5, however, results in a decrease of 16.76% in reliability at the locations of the reservoirs as compared to scenario 5.08. The run-of-river rights in Table 5.33 have an overall decrease of 5.9% between scenarios 5.08 and 5.14.

Table 5.34 presents water balance makeup for each scenario. As compared with the scenario without forecasting, the scenarios using forecasting methods 1 and 3 show a slight decrease in the amount of water balance makeup that occurs during the simulation. The scenario using forecasting method 5 nearly eliminates all occurrences of water balance makeup.

Table 5.30 End-of-day Storage Frequency for Scenarios 5.08, 5.11, 5.13, and 5.14, ac-ft

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.08, No Forecasting											
515531	633117.	97579.	218468.	373546.	450143.	490128.	578876.	664988.	713850.	724541.	724739.
515631	133553.	26008.	36596.	57263.	72475.	97595.	121399.	143696.	154188.	155000.	155000.
515731	591271.	54946.	365112.	407255.	451365.	522237.	577696.	607028.	630332.	635745.	636100.
515831	41000.	11930.	0.	4316.	15564.	23926.	36055.	44638.	50164.	52071.	52400.
509431	158176.	47017.	8510.	38143.	57646.	80479.	135835.	172650.	195978.	201864.	206562.
516531	174609.	54500.	0.	20496.	47519.	90952.	151423.	191492.	218206.	222733.	225400.
515931	42500.	15823.	0.	3615.	7849.	18640.	33596.	44865.	56954.	59393.	59400.
516031	375705.	110735.	0.	17977.	94813.	212970.	355511.	416125.	452731.	457600.	457600.
516131	181743.	69537.	0.	0.	364.	37235.	165258.	209298.	231372.	235700.	235700.
516231	27344.	11111.	0.	0.	295.	9092.	20775.	31971.	36043.	37100.	37100.
516331	53377.	17266.	0.	1033.	11007.	27158.	48319.	61971.	65500.	65500.	65500.
516431	129898.	36067.	0.	30227.	55981.	71225.	113618.	142781.	159740.	160110.	160110.
Total	2542291.	479728.	957754.	1121952.	1442010.	1775366.	2367310.	2691557.	2900170.	2981422.	3015611.
Scenario 5.11, Forecasting Method 1											
515531	634959.	97122.	219600.	374410.	455452.	492110.	581260.	668389.	715492.	724701.	724739.
515631	130268.	30417.	0.	42056.	56762.	89681.	118274.	141495.	153641.	155000.	155000.
515731	581149.	61066.	339912.	380865.	425201.	503125.	564464.	599114.	624279.	635092.	636100.
515831	39285.	13707.	0.	0.	5303.	17621.	33728.	43664.	50098.	51426.	52400.
509431	153882.	47409.	6713.	31953.	51959.	76544.	130532.	167702.	192442.	199128.	206562.
516531	172304.	55817.	0.	14912.	40610.	86135.	148044.	189642.	216928.	221641.	225400.
515931	39576.	17688.	0.	229.	5302.	13528.	26596.	42906.	56586.	59185.	59400.
516031	365227.	121243.	0.	0.	40301.	191943.	337705.	410157.	453589.	457600.	457600.
516131	180389.	70593.	0.	0.	0.	30511.	163247.	208332.	232231.	235700.	235700.
516231	26696.	11623.	0.	0.	0.	6564.	19769.	31503.	36281.	37100.	37100.
516331	52148.	18199.	0.	0.	7278.	23533.	46858.	60604.	65500.	65500.	65500.
516431	127699.	38157.	0.	17823.	50586.	66582.	109377.	140749.	159701.	160110.	160110.
Total	2503584.	509570.	914872.	1011832.	1325202.	1684470.	2305935.	2663584.	2885680.	2970592.	3015611.
Scenario 5.13, Forecasting Method 3											
515531	635901.	96475.	220825.	375727.	456502.	494428.	581954.	669441.	716064.	724729.	724739.
515631	131451.	28794.	12378.	49139.	63389.	90956.	119489.	142527.	153872.	155000.	155000.
515731	584652.	58547.	348518.	391098.	438290.	508916.	568674.	601333.	627235.	635493.	636100.
515831	40178.	12868.	0.	0.	9978.	21453.	34808.	44029.	50527.	51675.	52400.
509431	154525.	47224.	7098.	33421.	53192.	77416.	131006.	168312.	192673.	199882.	206562.
516531	172508.	55393.	0.	16294.	42635.	87261.	148508.	189506.	216847.	221384.	225400.
515931	39834.	16932.	0.	1029.	6411.	14764.	27905.	43100.	55085.	58689.	59400.
516031	366230.	118046.	0.	0.	56491.	190998.	340586.	408084.	450642.	457600.	457600.
516131	179443.	69722.	0.	0.	0.	35423.	160389.	206588.	230251.	235700.	235700.
516231	26645.	11303.	0.	0.	0.	8391.	19550.	31081.	35880.	37095.	37100.
516331	52416.	17712.	0.	0.	9065.	25382.	46627.	60570.	65418.	65500.	65500.
516431	128155.	37545.	0.	22517.	52130.	66993.	110350.	140883.	159705.	160110.	160110.
Total	2511938.	496675.	934038.	1060513.	1376869.	1706336.	2321629.	2662972.	2887449.	2969492.	3015611.

Table 5.30 Continued

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.14, Forecasting Method 5											
515531	318443.	206924.	0.	0.	0.	16866.	133238.	332713.	479507.	581129.	724739.
515631	39582.	51234.	0.	0.	0.	0.	0.	6559.	79991.	128935.	155000.
515731	278811.	147782.	108137.	121969.	133761.	142489.	166692.	226140.	365151.	543328.	636006.
515831	6916.	12541.	0.	0.	0.	0.	0.	0.	8557.	28081.	52400.
509431	43650.	44521.	2.	15.	98.	318.	10677.	28881.	63123.	107066.	206562.
516531	96865.	72480.	0.	0.	0.	0.	22927.	95782.	157308.	197969.	225400.
515931	15224.	19430.	0.	0.	0.	0.	0.	3009.	32286.	46986.	59400.
516031	234091.	155163.	0.	0.	0.	0.	97196.	255082.	374520.	434178.	457600.
516131	99260.	80538.	0.	0.	0.	0.	24931.	81482.	177124.	221712.	235700.
516231	12214.	12000.	0.	0.	0.	0.	0.	8936.	22750.	29615.	37100.
516331	26893.	21329.	0.	0.	0.	0.	3637.	27397.	45796.	55285.	65500.
516431	122935.	42533.	0.	0.	21715.	53307.	104179.	136596.	157819.	160110.	160110.
Total	1294884.	662676.	211796.	299368.	382576.	502770.	775068.	1199196.	1754882.	2300460.	3014204.

Table 5.31 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.08, 5.11, 5.13, and 5.14

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	100%	95%	90%	75%	50%	25%	1%
					% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT						
Scenario 5.08, No Forecasting											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							

Table 5.31 Continued

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
			Scenario 5.11, Forecasting Method 1								
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	27.10	99.86	99.96	99.9	99.9	99.9	99.9	100.0	100.0	100.0
515731	18243.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	382.11	96.84	97.25	96.8	96.8	97.0	97.0	97.0	97.3	97.7
509431	97907.4	4677.65	88.94	95.22	88.9	89.1	89.5	90.7	98.3	99.4	100.0
516531	65074.0	645.74	98.71	99.01	98.7	98.7	98.7	98.7	99.0	99.0	99.1
515931	19658.0	349.76	97.41	98.22	97.4	97.6	97.6	98.0	98.3	98.6	99.3
516031	112257.0	2243.82	96.98	98.00	97.0	97.0	97.1	97.1	97.4	98.1	98.7
516131	67768.0	3660.58	93.25	94.60	93.2	93.2	93.2	93.4	93.8	95.5	96.3
516231	13610.0	771.36	93.39	94.33	93.4	93.4	93.4	93.5	93.5	94.3	96.3
516331	19840.0	480.37	96.98	97.58	97.0	97.0	97.0	97.0	97.3	98.0	98.3
516431	48000.0	400.40	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.3
Total	771715.9	13638.92		98.23							
			Scenario 5.13, Forecasting Method 3								
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18313.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	277.32	97.84	98.00	97.8	97.8	97.8	97.8	97.8	98.0	98.4
509431	97999.3	4593.62	89.22	95.31	89.2	89.2	89.8	90.8	98.3	99.4	100.0
516531	65074.0	593.32	98.85	99.09	98.9	98.9	98.9	98.9	99.0	99.0	99.3
515931	19658.0	275.56	98.13	98.60	98.1	98.1	98.1	98.4	98.7	99.1	99.7
516031	112257.0	1840.51	97.27	98.36	97.3	97.4	97.6	97.6	97.8	98.4	98.9
516131	67768.0	3369.20	93.68	95.03	93.7	93.7	93.7	93.8	94.4	95.7	96.7
516231	13610.0	682.47	93.97	94.99	94.0	94.0	94.0	94.1	94.4	95.4	96.8
516331	19840.0	395.71	97.27	98.01	97.3	97.3	97.3	97.6	97.8	98.4	98.6
516431	48000.0	328.12	98.85	99.32	98.9	98.9	98.9	98.9	98.9	99.3	99.4
Total	771878.1	12355.87		98.40							
			Scenario 5.14, Forecasting Method 5								
515531	230750.0	14808.53	90.95	93.58	90.9	90.9	90.9	91.5	92.8	94.7	97.8
515631	64712.0	27368.22	52.01	57.71	52.0	52.2	52.9	54.0	56.8	58.8	64.7
515731	4199.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	8048.75	37.93	42.08	37.9	38.5	38.9	40.7	43.1	45.0	51.9
509431	94641.1	36095.62	20.83	61.86	20.8	21.6	23.0	25.9	65.1	87.4	93.8
516531	65074.0	9889.96	82.61	84.80	82.6	82.6	82.6	83.2	85.3	86.2	88.9
515931	19658.0	8200.14	53.16	58.29	53.2	53.4	53.6	54.6	57.2	60.1	64.9
516031	112257.0	13796.15	85.78	87.71	85.8	86.1	86.4	86.6	87.5	88.2	90.2
516131	67768.0	8800.23	85.06	87.01	85.1	85.2	85.8	85.9	86.4	87.5	90.4
516231	13610.0	4165.56	67.10	69.39	67.1	67.5	67.7	68.8	70.1	71.3	73.6
516331	19840.0	4182.67	76.87	78.92	76.9	77.6	77.7	78.4	79.5	80.0	81.5
516431	48000.0	862.82	97.56	98.20	97.6	97.6	97.6	97.8	97.8	98.1	98.4
Total	754405.1	136218.64		81.94							

Table 5.32 Mean Shortage for Selected Run-of-river Water Rights for Scenarios 5.08, 5.11, 5.13, and 5.14

Selected Water Rights	Target Diversion	Mean Annual Shortage, ac-ft per year			
	ac-ft per year	5.08	5.11	5.13	5.14
Dec. 31, 1929, and Senior, all uses	120,722	10,090	7,212	7,510	14,858
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	8,020	6,018	6,137	8,820
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	36,433	33,020	33,280	34,361
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	25,967	27,522	27,334	34,743
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	34,174	30,991	31,176	28,848
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,462	1,566	1,536	2,174
Jan. 1, 1980, and Junior, municipal use	75,000	16,109	16,927	15,537	48,682
Jan. 1, 1980, and Junior, non-municipal use	84,261	32,912	32,095	32,127	39,504
All Selected Water Rights	790,221	165,165	155,352	154,638	211,990

Table 5.33 Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.08, 5.11, 5.13, and 5.14

Selected Water Rights	Volume Reliability, %			
	5.08	5.11	5.13	5.14
Dec. 31, 1929, and Senior, all uses	91.6	94.0	93.8	87.7
Jan. 1, 1930, to Dec. 31, 1939, all uses	89.4	92.0	91.9	88.3
Jan. 1, 1940, to Dec. 31, 1949, all uses	81.0	82.8	82.7	82.1
Jan. 1, 1950, to Dec. 31, 1959, all uses	76.9	75.5	75.6	69.0
Jan. 1, 1960, to Dec. 31, 1969, all uses	72.8	75.4	75.2	77.1
Jan. 1, 1970, to Dec. 31, 1979, all uses	68.9	66.6	67.3	53.7
Jan. 1, 1980, and Junior, municipal use	78.5	77.4	79.3	35.1
Jan. 1, 1980, and Junior, non-municipal use	60.9	61.9	61.9	53.1
All Selected Water Rights	79.1	80.3	80.4	73.2

Table 5.34 Water Balance Makeup at Selected Control Points for Scenarios 5.08, 5.11, 5.13, and 5.14

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.08, No Forecasting			
BRBR59	Bryan Gage	-1,190.6	-0.030	-2,356.5	-0.113
BRHE68	Hempstead Gage	-1,608.0	-0.030	-3,157.2	-0.111
BRRI70	Richmond Gage	-1,496.7	-0.026	-2,801.0	-0.089
LRCA58	Cameron Gage	-46.1	-0.003	-92.2	-0.017
BRGM73	Gulf Outlet	-691.7	-0.011	-1,233.0	-0.038
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-837.9	-0.077	-1,136.2	-0.195
515731	Whitney Lake	-544.6	-0.040	-368.3	-0.049
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.6	0.000	-0.3	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-50.6	-0.010	-99.6	-0.052
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.4	0.000	-0.8	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.11, Forecasting Method 1			
BRBR59	Bryan Gage	-871.2	-0.022	-1,742.4	-0.084
BRHE68	Hempstead Gage	-940.6	-0.018	-1,880.8	-0.066
BRRI70	Richmond Gage	-844.7	-0.014	-1,636.4	-0.052
LRCA58	Cameron Gage	-4.3	0.000	-8.6	-0.002
BRGM73	Gulf Outlet	-285.7	-0.005	-544.7	-0.017
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-505.6	-0.046	-705.3	-0.121
515731	Whitney Lake	-423.2	-0.031	-213.2	-0.028
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-1.9	-0.001	-1.7	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-1.2	0.000	-2.2	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-1.2	-0.001	-2.3	-0.004
516431	Somerville Lake	0.0	0.000	0.0	0.000

Table 5.34 Continued

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.13, Forecasting Method 3			
BRBR59	Bryan Gage	-937.4	-0.023	-1,874.3	-0.090
BRHE68	Hempstead Gage	-1,165.6	-0.022	-2,322.9	-0.081
BRRI70	Richmond Gage	-1,049.1	-0.018	-2,014.2	-0.064
LRCA58	Cameron Gage	-11.2	-0.001	-22.4	-0.004
BRGM73	Gulf Outlet	-436.3	-0.007	-787.3	-0.024
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-550.8	-0.050	-760.4	-0.131
515731	Whitney Lake	-453.4	-0.033	-238.6	-0.031
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-2.1	-0.001	-1.5	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-2.1	0.000	-4.0	-0.002
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-1.2	-0.001	-2.5	-0.004
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.14, Forecasting Method 5			
BRBR59	Bryan Gage	0.0	0.000	0.0	0.000
BRHE68	Hempstead Gage	0.0	0.000	0.0	0.000
BRRI70	Richmond Gage	0.0	0.000	0.0	0.000
LRCA58	Cameron Gage	0.0	0.000	-0.1	0.000
BRGM73	Gulf Outlet	0.0	0.000	0.0	0.000
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-8.9	-0.001	-13.3	-0.002
515731	Whitney Lake	-0.1	0.000	-0.2	0.000
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-1.8	-0.001	-1.6	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-0.1	0.000	-0.2	0.000
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	0.0	0.000	0.0	0.000
516431	Somerville Lake	0.0	0.000	0.0	0.000

The results presented above indicate a slight sensitivity of the simulation to forecasting methods 1 and 3 when a 3-day forecasting period is applied to all water rights. Reservoir storage frequency is the most sensitive to forecasting during the extreme drawdown periods of the simulation. For example, the 50% exceedances for Belton Lake are 416,125, 410,157, and 408,084 ac-ft for the scenarios without forecasting, forecasting method 1 and method 3, respectively. However, the 95% exceedances for Belton Lake are 94,813, 40,301, and 56,491 ac-ft for the scenarios without forecasting, forecasting method 1 and method 3, respectively. Belton refills with a priority date of December 16, 1963, and serves 112,257 ac-ft per year of water right demand. Forecasting for downstream senior water right shortages impairs reservoir refilling during the most water limited time steps of the simulation. Run-of-river reliability and water balance makeup generally improve with the application of the 3-day forecasting period. Short forecasting periods may improve the convergence of water right depletions toward a steady state during extended low flow and water limited periods of the simulation.

Forecasting method 5 results in significant impairment of the water rights' ability to meet target demands and to refill storage. Forecasting method 5 should be used with caution and on a case-by-case basis when specific water management practices require a water right to forgo streamflow depletions when future downstream shortages are encountered. Shorter forecasting periods may also be appropriate with forecasting method 5. Water right depletions may have difficulty reaching a steady state during extended low flow and water limited periods of the simulation due to the binary and complete curtailment of water availability used by forecasting method 5.

5.6 Forecasting Periods

Forecast periods are examined in this section. Forecast periods are increased from 1 day to a maximum of 7 days for all water rights. All scenarios with forecasting periods use forecasting method 1. Scenario 5.17 varies the forecast periods for water rights according to priority date. Water rights with the most junior priority date are sub-divided into municipal and non-municipal rights. Non-municipal rights with the most junior priority are assigned the longest forecasting period. Table 4.11 lists the criteria for assigning forecasting periods in scenario 5.17. All scenarios use routing option WRMETH 1 to place routed changes to flow before the priority loop each day. Table 5.35 lists the parameters of the simulation scenarios considered in this section.

Table 5.35 Parameters per Simulation Scenario in Section 5.6

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na
5.10	day	Bwam3	lag-att	1	daily pattern	uniform	1 day	1
5.11	day	Bwam3	lag-att	1	daily pattern	uniform	3 days	1
5.15	day	Bwam3	lag-att	1	daily pattern	uniform	5 days	1
5.16	day	Bwam3	lag-att	1	daily pattern	uniform	7 days	1
5.17	day	Bwam3	lag-att	1	daily pattern	uniform	Table 4.11	1

Results for daily storage frequency and water right reliability generally show only slight sensitivity to forecasting period. When applying the same forecasting period to all water rights, reliability increases up to the 5-day global forecast period. A global forecast period of 7 days begins to impair overall water availability. All forecast periods reduce the occurrence of water balance makeup over the scenario without forecasting. Tables 5.36, 5.37, 5.38, 5.39, and 5.40 present the results for end-of-day storage frequency, reservoir right reliability, run-of-river right shortage, run-of-river right reliability, and water balance makeup, respectively.

The varied forecast period setting for scenario 5.17 according to the criteria in Table 4.11 is an example of an approach to balance the multi-objective optimization of:

- minimizing impacts to senior right water availability caused by junior right streamflow depletions in previous days;
- minimizing constraints on water availability with excessive forecast periods, especially for junior water rights;
- allowing adequate reservoir refilling to minimize storage shortages during drought periods; and
- minimizing over-appropriation within the model that triggers occurrences of water balance makeup.

Forecast periods in scenario 5.17 are not assigned according to location or relative distance to the downstream senior right(s). By assigning an ascending forecast period based on ascending priority number, the most junior rights in the basin are always curtailed first. Curtailment of the most junior rights reduces the likelihood of more senior rights being curtailed, regardless of their relative location, to meet the needs of the downstream senior-most rights.

Table 5.36 End-of-day Storage Frequency for Scenarios 5.08, 5.10, 5.11, 5.15, 5.16, and 5.17

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.08, No Forecasting											
515531	633117.	97579.	218468.	373546.	450143.	490128.	578876.	664988.	713850.	724541.	724739.
515631	133553.	26008.	36596.	57263.	72475.	97595.	121399.	143696.	154188.	155000.	155000.
515731	591271.	54946.	365112.	407255.	451365.	522237.	577696.	607028.	630332.	635745.	636100.
515831	41000.	11930.	0.	4316.	15564.	23926.	36055.	44638.	50164.	52071.	52400.
509431	158176.	47017.	8510.	38143.	57646.	80479.	135835.	172650.	195978.	201864.	206562.
516531	174609.	54500.	0.	20496.	47519.	90952.	151423.	191492.	218206.	222733.	225400.
515931	42500.	15823.	0.	3615.	7849.	18640.	33596.	44865.	56954.	59393.	59400.
516031	375705.	110735.	0.	17977.	94813.	212970.	355511.	416125.	452731.	457600.	457600.
516131	181743.	69537.	0.	0.	364.	37235.	165258.	209298.	231372.	235700.	235700.
516231	27344.	11111.	0.	0.	295.	9092.	20775.	31971.	36043.	37100.	37100.
516331	53377.	17266.	0.	1033.	11007.	27158.	48319.	61971.	65500.	65500.	65500.
516431	129898.	36067.	0.	30227.	55981.	71225.	113618.	142781.	159740.	160110.	160110.
Total	2542291.	479728.	957754.	1121952.	1442010.	1775366.	2367310.	2691557.	2900170.	2981422.	3015611.
Scenario 5.10, 1-Day Forecasting Period											
515531	635142.	96866.	217903.	372578.	455670.	494096.	580621.	668054.	715410.	724665.	724739.
515631	130658.	29279.	8822.	45672.	61679.	90433.	118764.	141820.	153480.	155000.	155000.
515731	585935.	55959.	358233.	403133.	445146.	514322.	568981.	601835.	625714.	634594.	636100.
515831	39803.	13170.	0.	0.	7507.	20491.	34370.	43830.	49879.	51774.	52400.
509431	154723.	47235.	7405.	33152.	52606.	77138.	131833.	168794.	192691.	199478.	206562.
516531	172368.	56322.	0.	13874.	39484.	85986.	147786.	190113.	217432.	222159.	225400.
515931	40509.	17246.	0.	805.	6201.	15061.	28952.	43395.	57040.	59354.	59400.
516031	368912.	118706.	0.	0.	53862.	201642.	342407.	413173.	454246.	457600.	457600.
516131	181185.	70274.	0.	0.	0.	34586.	164449.	208904.	232591.	235700.	235700.
516231	26972.	11485.	0.	0.	0.	7664.	20075.	31815.	36317.	37100.	37100.
516331	52549.	18130.	0.	0.	7272.	24261.	47406.	61219.	65500.	65500.	65500.
516431	128154.	37614.	0.	21015.	51975.	67133.	110351.	140904.	159704.	160110.	160110.
Total	2516909.	499128.	935263.	1051013.	1367711.	1717315.	2326104.	2672947.	2891246.	2973758.	3015611.
Scenario 5.11, 3-Day Forecasting Period											
515531	634959.	97122.	219600.	374410.	455452.	492110.	581260.	668389.	715492.	724701.	724739.
515631	130268.	30417.	0.	42056.	56762.	89681.	118274.	141495.	153641.	155000.	155000.
515731	581149.	61066.	339912.	380865.	425201.	503125.	564464.	599114.	624279.	635092.	636100.
515831	39285.	13707.	0.	0.	5303.	17621.	33728.	43664.	50098.	51426.	52400.
509431	153882.	47409.	6713.	31953.	51959.	76544.	130532.	167702.	192442.	199128.	206562.
516531	172304.	55817.	0.	14912.	40610.	86135.	148044.	189642.	216928.	221641.	225400.
515931	39576.	17688.	0.	229.	5302.	13528.	26596.	42906.	56586.	59185.	59400.
516031	365227.	121243.	0.	0.	40301.	191943.	337705.	410157.	453589.	457600.	457600.
516131	180389.	70593.	0.	0.	0.	30511.	163247.	208332.	232231.	235700.	235700.
516231	26696.	11623.	0.	0.	0.	6564.	19769.	31503.	36281.	37100.	37100.
516331	52148.	18199.	0.	0.	7278.	23533.	46858.	60604.	65500.	65500.	65500.
516431	127699.	38157.	0.	17823.	50586.	66582.	109377.	140749.	159701.	160110.	160110.
Total	2503584.	509570.	914872.	1011832.	1325202.	1684470.	2305935.	2663584.	2885680.	2970592.	3015611.

Table 5.36 Continued

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
			% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.15, 5-Day Forecasting Period											
515531	635443.	97844.	218223.	374800.	453309.	490676.	582044.	669410.	716746.	724739.	724739.
515631	129775.	31087.	0.	40068.	55239.	88121.	117462.	141121.	153969.	155000.	155000.
515731	576736.	66718.	317664.	361368.	404578.	490924.	558481.	596992.	623954.	633644.	636100.
515831	38854.	13673.	0.	0.	5802.	17440.	32996.	43242.	49463.	51281.	52400.
509431	152988.	47773.	6804.	31842.	50712.	74509.	129640.	167343.	192390.	198712.	206562.
516531	172360.	56033.	0.	14371.	40135.	85518.	147917.	189828.	217096.	221750.	225400.
515931	38850.	17767.	0.	0.	5099.	12495.	25145.	42418.	55170.	59128.	59400.
516031	360659.	123282.	0.	0.	30656.	182130.	333035.	403668.	449425.	457600.	457600.
516131	177703.	70611.	0.	0.	0.	28472.	157284.	205290.	229753.	235700.	235700.
516231	25951.	11654.	0.	0.	0.	5674.	18665.	30404.	35598.	36927.	37100.
516331	51397.	18471.	0.	0.	5787.	21903.	45574.	59789.	65091.	65500.	65500.
516431	126969.	38926.	0.	14558.	47773.	64297.	108402.	140168.	159670.	160110.	160110.
Total	2487684.	520794.	891681.	976901.	1273545.	1643163.	2282971.	2649438.	2879784.	2965821.	3015611.
Scenario 5.16, 7-Day Forecasting Period											
515531	633977.	97773.	217523.	373804.	451252.	488650.	579503.	667505.	713168.	724345.	724739.
515631	127694.	32301.	0.	32025.	52794.	84591.	114216.	138944.	152357.	155000.	155000.
515731	560712.	71318.	300301.	341880.	385646.	478516.	535030.	578378.	614998.	632758.	636100.
515831	38201.	13748.	0.	0.	5404.	16619.	32059.	42540.	48703.	51271.	52400.
509431	151088.	48031.	6419.	30747.	49040.	71916.	127561.	165824.	190544.	197935.	206562.
516531	171538.	56198.	0.	12739.	38498.	84536.	147273.	188854.	216116.	221357.	225400.
515931	37199.	18278.	0.	0.	1608.	9522.	22037.	41375.	53420.	58827.	59400.
516031	352682.	122944.	0.	0.	26368.	167852.	322691.	393332.	437557.	457600.	457600.
516131	171516.	69677.	0.	0.	0.	27716.	145535.	197018.	222395.	234411.	235700.
516231	24809.	11645.	0.	0.	0.	5119.	16685.	28880.	34480.	36651.	37100.
516331	50300.	18476.	0.	0.	5108.	20798.	43948.	58320.	63941.	65500.	65500.
516431	125852.	39987.	0.	8120.	42610.	62431.	106760.	139275.	159552.	160110.	160110.
Total	2445567.	523209.	844280.	957931.	1236324.	1596732.	2238605.	2599110.	2832813.	2940277.	3015611.
Scenario 5.17, Varied Forecasting Period											
515531	636111.	97125.	217069.	373938.	455970.	494879.	582325.	669854.	717068.	724739.	724739.
515631	130241.	29686.	7510.	44212.	59426.	89335.	118326.	141577.	153273.	155000.	155000.
515731	575795.	67526.	316068.	359608.	396827.	488689.	558949.	596345.	622800.	634115.	636100.
515831	38945.	13988.	0.	0.	3905.	16067.	33489.	43485.	49959.	51291.	52400.
509431	154279.	46895.	8082.	34398.	53174.	77655.	131846.	167910.	192505.	199226.	206562.
516531	172458.	55957.	0.	14564.	40080.	86769.	148462.	189810.	217137.	222028.	225400.
515931	39738.	17719.	0.	233.	5917.	13549.	26205.	43163.	56474.	59327.	59400.
516031	366976.	119692.	0.	0.	48669.	195835.	339372.	411311.	453627.	457600.	457600.
516131	180779.	70603.	0.	0.	0.	31212.	163727.	208689.	232726.	235700.	235700.
516231	26881.	11583.	0.	0.	0.	6941.	19983.	31736.	36390.	37100.	37100.
516331	52389.	18090.	0.	0.	7669.	24339.	47013.	60917.	65500.	65500.	65500.
516431	128039.	37700.	0.	20378.	51944.	67201.	110188.	140845.	159698.	160110.	160110.
Total	2502630.	514450.	890572.	995540.	1305182.	1682549.	2305097.	2664322.	2887446.	2969990.	3015611.

Table 5.37 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.08, 5.10, 5.11, 5.15, 5.16, and 5.17

Scenario 5.08, No Forecasting

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							

Scenario 5.10, 1-Day Forecasting Period

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	100%	95%	90%	75%	50%	25%	1%
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18369.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	335.54	97.27	97.59	97.3	97.3	97.4	97.4	97.4	97.6	97.8
509431	97908.0	4571.72	88.94	95.33	88.9	88.9	89.4	90.9	98.4	99.4	100.0
516531	65074.0	667.61	98.71	98.97	98.7	98.7	98.7	98.7	98.9	99.0	99.1
515931	19658.0	274.18	97.70	98.61	97.7	97.8	97.8	98.4	98.7	99.1	99.4
516031	112257.0	1960.67	97.27	98.25	97.3	97.3	97.4	97.4	97.6	98.3	98.9
516131	67768.0	3552.57	93.53	94.76	93.5	93.5	93.5	93.7	94.1	95.4	96.8
516231	13610.0	720.85	93.68	94.70	93.7	93.7	93.7	93.8	94.1	95.0	96.6
516331	19840.0	475.94	96.84	97.60	96.8	96.8	97.0	97.0	97.3	97.8	98.3
516431	48000.0	345.08	98.85	99.28	98.9	98.9	98.9	98.9	98.9	99.3	99.7
Total	771842.8	12904.19		98.33							

Scenario 5.11, 3-Day Forecasting Period

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	100%	95%	90%	75%	50%	25%	1%
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	27.10	99.86	99.96	99.9	99.9	99.9	99.9	100.0	100.0	100.0
515731	18243.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	382.11	96.84	97.25	96.8	96.8	97.0	97.0	97.0	97.3	97.7
509431	97907.4	4677.65	88.94	95.22	88.9	89.1	89.5	90.7	98.3	99.4	100.0
516531	65074.0	645.74	98.71	99.01	98.7	98.7	98.7	98.7	99.0	99.0	99.1
515931	19658.0	349.76	97.41	98.22	97.4	97.6	97.6	98.0	98.3	98.6	99.3
516031	112257.0	2243.82	96.98	98.00	97.0	97.0	97.1	97.1	97.4	98.1	98.7
516131	67768.0	3660.58	93.25	94.60	93.2	93.2	93.2	93.4	93.8	95.5	96.3
516231	13610.0	771.36	93.39	94.33	93.4	93.4	93.4	93.5	93.5	94.3	96.3
516331	19840.0	480.37	96.98	97.58	97.0	97.0	97.0	97.0	97.3	98.0	98.3
516431	48000.0	400.40	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.3
Total	771715.9	13638.92		98.23							

Table 5.37 Continued

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
Scenario 5.15, 5-Day Forecasting Period											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	72.90	99.71	99.89	99.7	99.7	99.7	99.7	100.0	100.0	100.0
515731	18063.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	383.14	96.70	97.24	96.7	96.7	96.8	96.8	97.0	97.4	97.7
509431	97802.5	4926.19	88.51	94.96	88.5	88.5	88.9	90.1	98.1	99.4	100.0
516531	65074.0	655.51	98.71	98.99	98.7	98.7	98.7	98.7	99.0	99.0	99.1
515931	19658.0	415.51	96.98	97.89	97.0	97.0	97.3	97.7	98.0	98.6	99.0
516031	112257.0	2572.17	96.70	97.71	96.7	96.7	96.8	97.0	97.4	97.8	98.4
516131	67768.0	3924.39	92.82	94.21	92.8	92.8	92.8	93.1	93.7	95.0	95.8
516231	13610.0	825.99	92.96	93.93	93.0	93.0	93.0	93.2	93.2	94.0	95.3
516331	19840.0	569.44	96.26	97.13	96.3	96.3	96.3	96.4	96.7	97.4	97.7
516431	48000.0	473.33	98.71	99.01	98.7	98.7	98.7	98.7	98.7	99.0	99.1
Total	771430.8	14818.59		98.08							
Scenario 5.16, 7-Day Forecasting Period											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	244.14	99.28	99.62	99.3	99.3	99.3	99.3	99.4	99.7	100.0
515731	17639.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	379.31	96.84	97.27	96.8	96.8	96.8	96.8	97.1	97.3	97.7
509431	97774.5	5125.65	87.79	94.76	87.8	87.8	88.4	89.9	97.8	99.4	100.0
516531	65074.0	720.08	98.71	98.89	98.7	98.7	98.7	98.7	98.9	98.9	99.0
515931	19658.0	566.49	95.69	97.12	95.7	95.7	95.7	96.0	96.8	97.6	98.0
516031	112257.0	2746.10	96.55	97.55	96.6	96.6	96.7	96.8	97.3	97.7	98.3
516131	67768.0	3983.93	92.82	94.12	92.8	92.8	92.8	92.8	93.5	95.0	95.8
516231	13610.0	853.32	92.53	93.73	92.5	92.7	92.8	93.0	93.1	93.8	94.8
516331	19840.0	583.81	95.98	97.06	96.0	96.1	96.3	96.4	96.6	97.4	97.7
516431	48000.0	593.46	98.56	98.76	98.6	98.6	98.6	98.6	98.7	98.9	98.9
Total	770978.6	15796.32		97.95							
Scenario 5.17, Varied Forecasting Period											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18077.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	427.09	96.41	96.93	96.4	96.4	96.4	96.4	96.4	97.1	97.6
509431	97680.1	4557.20	88.79	95.33	88.8	88.9	89.5	90.5	98.3	99.6	100.0
516531	65074.0	656.26	98.71	98.99	98.7	98.7	98.7	98.7	99.0	99.0	99.1
515931	19658.0	383.75	97.41	98.05	97.4	97.4	97.4	97.7	98.3	98.9	99.3
516031	112257.0	2066.31	97.13	98.16	97.1	97.1	97.3	97.3	97.6	98.1	98.9
516131	67768.0	3639.82	93.10	94.63	93.1	93.4	93.5	93.5	94.0	95.4	96.6
516231	13610.0	754.91	93.53	94.45	93.5	93.5	93.5	93.7	93.7	94.5	96.3
516331	19840.0	478.51	96.84	97.59	96.8	96.8	96.8	96.8	97.3	98.0	98.1
516431	48000.0	360.95	98.85	99.25	98.9	98.9	98.9	98.9	98.9	99.1	99.4
Total	771322.9	13324.83		98.27							

Table 5.38 Mean Shortage for Selected Run-of-river Water Rights for Scenarios 5.08, 5.10, 5.11, 5.15, 5.16, and 5.17

Selected Water Rights	Target Diversion	Mean Annual Shortage, ac-ft per year					
	ac-ft per year	5.08	5.10	5.11	5.15	5.16	5.17
Dec. 31, 1929, and Senior, all uses	120,722	10,090	7,928	7,212	6,784	6,587	7,582
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	8,020	6,481	6,018	5,740	5,634	6,213
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	36,433	34,113	33,020	32,801	33,298	33,260
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	25,967	27,395	27,522	27,865	28,379	27,466
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	34,174	32,116	30,991	30,351	30,079	31,311
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,462	1,570	1,566	1,567	1,590	1,588
Jan. 1, 1980, and Junior, municipal use	75,000	16,109	17,025	16,927	16,961	16,925	17,599
Jan. 1, 1980, and Junior, non-municipal use	84,261	32,912	32,563	32,095	31,586	31,203	32,755
All Selected Water Rights	790,221	165,165	159,191	155,352	153,655	153,694	157,775

Table 5.39 Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.08, 5.10, 5.11, 5.15, 5.16, and 5.17

Selected Water Rights	Volume Reliability, %					
	5.08	5.10	5.11	5.15	5.16	5.17
Dec. 31, 1929, and Senior, all uses	91.6	93.4	94.0	94.4	94.5	93.7
Jan. 1, 1930, to Dec. 31, 1939, all uses	89.4	91.4	92.0	92.4	92.5	91.8
Jan. 1, 1940, to Dec. 31, 1949, all uses	81.0	82.2	82.8	82.9	82.7	82.7
Jan. 1, 1950, to Dec. 31, 1959, all uses	76.9	75.6	75.5	75.2	74.7	75.5
Jan. 1, 1960, to Dec. 31, 1969, all uses	72.8	74.5	75.4	75.9	76.1	75.1
Jan. 1, 1970, to Dec. 31, 1979, all uses	68.9	66.5	66.6	66.6	66.1	66.1
Jan. 1, 1980, and Junior, municipal use	78.5	77.3	77.4	77.4	77.4	76.5
Jan. 1, 1980, and Junior, non-municipal use	60.9	61.4	61.9	62.5	63.0	61.1
All Selected Water Rights	79.1	79.9	80.3	80.6	80.6	80.0

Table 5.40 Water Balance Makeup at Selected Control Points for Scenarios 5.08, 5.10, 5.11, 5.15, 5.16, and 5.17

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.08, No Forecasting			
BRBR59	Bryan Gage	-1,190.6	-0.030	-2,356.5	-0.113
BRHE68	Hempstead Gage	-1,608.0	-0.030	-3,157.2	-0.111
BRRI70	Richmond Gage	-1,496.7	-0.026	-2,801.0	-0.089
LRCA58	Cameron Gage	-46.1	-0.003	-92.2	-0.017
BRGM73	Gulf Outlet	-691.7	-0.011	-1,233.0	-0.038
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-837.9	-0.077	-1,136.2	-0.195
515731	Whitney Lake	-544.6	-0.040	-368.3	-0.049
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.6	0.000	-0.3	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-50.6	-0.010	-99.6	-0.052
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.4	0.000	-0.8	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.10, 1-Day Forecasting			
BRBR59	Bryan Gage	-943.9	-0.023	-1,884.9	-0.091
BRHE68	Hempstead Gage	-1,234.7	-0.023	-2,434.4	-0.085
BRRI70	Richmond Gage	-1,134.5	-0.019	-2,107.5	-0.067
LRCA58	Cameron Gage	-11.5	-0.001	-23.0	-0.004
BRGM73	Gulf Outlet	-520.1	-0.009	-934.2	-0.028
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-606.1	-0.055	-800.7	-0.138
515731	Whitney Lake	-437.3	-0.032	-246.1	-0.032
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.7	0.000	-0.4	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-1.3	0.000	-2.4	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-1.8	-0.001	-3.7	-0.006
516431	Somerville Lake	0.0	0.000	0.0	0.000

Table 5.40 Continued

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
		Scenario 5.11, 3-Day Forecasting			
BRBR59	Bryan Gage	-871.2	-0.022	-1,742.4	-0.084
BRHE68	Hempstead Gage	-940.6	-0.018	-1,880.8	-0.066
BRRI70	Richmond Gage	-844.7	-0.014	-1,636.4	-0.052
LRCA58	Cameron Gage	-4.3	0.000	-8.6	-0.002
BRGM73	Gulf Outlet	-285.7	-0.005	-544.7	-0.017
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-505.6	-0.046	-705.3	-0.121
515731	Whitney Lake	-423.2	-0.031	-213.2	-0.028
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-1.9	-0.001	-1.7	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-1.2	0.000	-2.2	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-1.2	-0.001	-2.3	-0.004
516431	Somerville Lake	0.0	0.000	0.0	0.000
		Scenario 5.15, 5-Day Forecasting			
BRBR59	Bryan Gage	-783.2	-0.019	-1,566.5	-0.075
BRHE68	Hempstead Gage	-775.9	-0.014	-1,551.8	-0.054
BRRI70	Richmond Gage	-697.1	-0.012	-1,394.2	-0.045
LRCA58	Cameron Gage	-11.1	-0.001	-22.2	-0.004
BRGM73	Gulf Outlet	-207.3	-0.003	-414.7	-0.013
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-459.9	-0.042	-646.7	-0.111
515731	Whitney Lake	-408.6	-0.030	-207.2	-0.027
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-2.5	-0.001	-2.8	-0.002
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-0.7	0.000	-1.3	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.4	0.000	-0.8	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000

Table 5.40 Continued

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
	Scenario 5.16, 7-Day Forecasting				
BRBR59	Bryan Gage	-775.5	-0.019	-1,550.9	-0.075
BRHE68	Hempstead Gage	-762.9	-0.014	-1,525.8	-0.053
BRRI70	Richmond Gage	-691.0	-0.012	-1,381.9	-0.044
LRCA58	Cameron Gage	-10.3	-0.001	-20.7	-0.004
BRGM73	Gulf Outlet	-215.4	-0.004	-430.8	-0.013
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-440.0	-0.040	-631.6	-0.109
515731	Whitney Lake	-408.7	-0.030	-224.9	-0.030
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-3.4	-0.001	-3.3	-0.002
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-0.7	0.000	-1.3	-0.001
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.3	0.000	-0.6	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000
	Scenario 5.17, Varied Forecasting Period				
BRBR59	Bryan Gage	-961.7	-0.024	-1,923.0	-0.092
BRHE68	Hempstead Gage	-1,129.2	-0.021	-2,258.4	-0.079
BRRI70	Richmond Gage	-1,022.0	-0.017	-1,990.7	-0.064
LRCA58	Cameron Gage	-10.1	-0.001	-20.2	-0.004
BRGM73	Gulf Outlet	-385.9	-0.006	-733.3	-0.022
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-576.0	-0.053	-786.3	-0.135
515731	Whitney Lake	-485.4	-0.036	-230.2	-0.030
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-1.9	-0.001	-1.5	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-2.3	0.000	-4.3	-0.002
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-3.1	-0.002	-6.2	-0.009
516431	Somerville Lake	0.0	0.000	0.0	0.000

5.7 Daily Water Right Target Distribution

The ND parameter is set for water rights according to their use type as listed in Table 4.12. Municipal use rights have a near-constant monthly demand and, accordingly, are assigned the highest value of ND. Fewer days for recovering shortages occur the closer the value of ND is to the actual number of days in the month. Agricultural use rights are assigned the lowest value of ND to reflect possible on-farm storage capacity or flexibility in diverting water whenever it becomes available during the month. Forecasting is combined with non-uniform target distribution to examine the effect of increasing the intra-month efficiency of diverting water while limiting water availability to protect downstream senior water rights. The parameters of the scenarios being considered in this section are presented in Table 5.41.

Table 5.41 Parameters per Simulation Scenario in Section 5.7

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	na
5.18	day	Bwam3	lag-att	1	daily pattern	Table 4.12	0 days	na
5.19	day	Bwam3	lag-att	1	daily pattern	Table 4.12	Table 4.11	1

Monthly target demands are established by the annual WR record target demand and the associated UC record set. The monthly demand is distributed uniformly over each day of the month by default. SIMD offers the option to set the number of days, ND, in which the target demand can be met. If ND is greater than zero, the monthly target demand will be distributed in the first ND days of the month. After the first ND days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target-building process if the SHORT parameter option is activated. Use of ND and SHORT enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

Tables 5.42, 5.43, 5.44, 5.45, and 5.46 present the results for end-of-day storage frequency, reservoir right reliability, run-of-river right shortage, run-of-river right reliability, and water balance makeup, respectively. Table 5.44 shows that mean shortages are decreased with the utilization of the ND and SHORT parameters in scenario 5.18. Shortages are decreased further for senior rights with a priority date senior to 1970 with the utilization of forecasting in scenario 5.19. Table 5.42 indicates that reservoir storage frequency is only slightly decreased on average with the utilization of ND, SHORT, and forecasting. Slight decreases in reservoir storage are related to the slight increases in the efficiency of water rights to make streamflow depletions when flow events pass through their reach of river. Increased water right reliability is an indicator of increased efficiency of water right capture of streamflow. Table 5.46 shows that water balance makeup is similar between scenarios 5.08 and 5.18. Scenarios 5.08 and 5.18 do not use forecasting. Water balance makeup decreases with the utilization of forecasting in scenario 5.19.

Table 5.42 End-of-day Storage Frequency for Scenarios 5.08, 5.18, and 5.19

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.08, Uniform Target Distribution, No Forecasting											
515531	633117.	97579.	218468.	373546.	450143.	490128.	578876.	664988.	713850.	724541.	724739.
515631	133553.	26008.	36596.	57263.	72475.	97595.	121399.	143696.	154188.	155000.	155000.
515731	591271.	54946.	365112.	407255.	451365.	522237.	577696.	607028.	630332.	635745.	636100.
515831	41000.	11930.	0.	4316.	15564.	23926.	36055.	44638.	50164.	52071.	52400.
509431	158176.	47017.	8510.	38143.	57646.	80479.	135835.	172650.	195978.	201864.	206562.
516531	174609.	54500.	0.	20496.	47519.	90952.	151423.	191492.	218206.	222733.	225400.
515931	42500.	15823.	0.	3615.	7849.	18640.	33596.	44865.	56954.	59393.	59400.
516031	375705.	110735.	0.	17977.	94813.	212970.	355511.	416125.	452731.	457600.	457600.
516131	181743.	69537.	0.	0.	364.	37235.	165258.	209298.	231372.	235700.	235700.
516231	27344.	11111.	0.	0.	295.	9092.	20775.	31971.	36043.	37100.	37100.
516331	53377.	17266.	0.	1033.	11007.	27158.	48319.	61971.	65500.	65500.	65500.
516431	129898.	36067.	0.	30227.	55981.	71225.	113618.	142781.	159740.	160110.	160110.
Total	2542291.	479728.	957754.	1121952.	1442010.	1775366.	2367310.	2691557.	2900170.	2981422.	3015611.
Scenario 5.18, Non-Uniform Monthly Target Distribution, No Forecasting											
515531	632427.	98936.	225300.	379575.	442097.	485267.	579814.	665692.	714764.	724708.	724739.
515631	132938.	27561.	25505.	48620.	67166.	95157.	121900.	143498.	154274.	155000.	155000.
515731	591119.	55653.	370710.	415918.	449530.	515312.	577779.	607390.	631850.	636066.	636100.
515831	41675.	12104.	0.	4656.	15829.	23719.	36938.	45335.	51631.	52400.	52400.
509431	157859.	47556.	8111.	35914.	55120.	80130.	135452.	172662.	196485.	202164.	206562.
516531	175256.	55263.	0.	19220.	45211.	90436.	151892.	192838.	219181.	224258.	225400.
515931	43018.	15915.	0.	3893.	8368.	18679.	33849.	45520.	58297.	59400.	59400.
516031	376043.	113151.	0.	10075.	85132.	214088.	354708.	417894.	456369.	457600.	457600.
516131	182655.	70202.	0.	0.	2.	35656.	166331.	210850.	233892.	235700.	235700.
516231	27863.	11249.	0.	0.	196.	9315.	21612.	32810.	37038.	37100.	37100.
516331	53197.	17565.	0.	338.	10257.	26453.	48370.	62005.	65500.	65500.	65500.
516431	129627.	36313.	0.	27802.	56170.	70804.	113320.	142469.	159524.	160110.	160110.
Total	2543677.	489813.	945583.	1095194.	1407175.	1771386.	2368266.	2700893.	2908666.	2988879.	3015611.
Scenario 5.19, Non-Uniform Monthly Target Distribution, with Forecasting											
515531	633333.	99662.	216556.	374980.	441209.	486429.	580033.	668401.	715515.	724580.	724739.
515631	129797.	31934.	0.	31919.	53705.	87817.	118182.	141776.	153945.	155000.	155000.
515731	578800.	67969.	323051.	366259.	401612.	489515.	561305.	599253.	627291.	635446.	636100.
515831	39129.	14195.	0.	0.	3402.	15780.	33738.	43819.	50244.	51687.	52400.
509431	155239.	47528.	7711.	34516.	52566.	77218.	133045.	169686.	194358.	200533.	206562.
516531	172235.	56638.	0.	12348.	38463.	85490.	147556.	189955.	217398.	222532.	225400.
515931	39349.	18013.	0.	0.	5076.	12450.	25186.	42968.	56644.	59400.	59400.
516031	364254.	121750.	0.	0.	41704.	183568.	335308.	409079.	455111.	457600.	457600.
516131	180842.	70574.	0.	0.	0.	32925.	162724.	208998.	233001.	235700.	235700.
516231	27041.	11663.	0.	0.	0.	6711.	20275.	32074.	36726.	37100.	37100.
516331	52216.	18358.	0.	0.	7288.	23316.	46973.	60874.	65500.	65500.	65500.
516431	127616.	38016.	0.	17851.	51047.	67782.	109567.	140682.	159462.	160110.	160110.
Total	2499851.	524700.	877586.	967693.	1258987.	1669852.	2304187.	2667879.	2891306.	2975584.	3015611.

Table 5.43 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.08, 5.18, and 5.19

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
Scenario 5.08, Uniform Target Distribution, No Forecasting											
515531	230750.0	0.03	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18437.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	180.10	98.56	98.70	98.6	98.6	98.6	98.6	98.6	98.9	99.4
509431	97951.0	4245.03	89.37	95.67	89.4	89.5	89.9	91.4	98.9	99.6	100.0
516531	65074.0	507.63	98.85	99.22	98.9	98.9	98.9	98.9	99.1	99.1	99.3
515931	19658.0	123.04	99.43	99.37	99.4	99.4	99.4	99.6	99.7	99.7	99.7
516031	112257.0	935.84	98.71	99.17	98.7	98.7	98.9	98.9	98.9	99.1	99.7
516131	67768.0	3023.24	94.25	95.54	94.3	94.3	94.3	94.4	95.1	96.1	98.1
516231	13610.0	565.77	94.40	95.84	94.4	94.4	94.7	94.8	95.5	96.4	98.1
516331	19840.0	276.52	97.84	98.61	97.8	97.8	98.0	98.1	98.3	99.0	99.4
516431	48000.0	198.26	98.99	99.59	99.0	99.0	99.0	99.1	99.1	99.4	100.0
Total	771953.8	10055.44		98.70							
Scenario 5.18, Non-Uniform Monthly Target Distribution, No Forecasting											
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18521.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13913.8	194.93	98.56	98.60	98.6	98.6	98.6	98.6	98.7	98.9	99.4
509431	98494.2	4651.55	88.94	95.28	88.9	89.1	89.5	91.2	98.4	99.4	100.0
516531	65278.2	711.19	98.85	98.91	98.9	98.9	98.9	98.9	99.0	99.1	99.3
515931	19750.9	199.94	99.43	98.99	99.4	99.4	99.4	99.7	99.7	99.7	99.7
516031	112400.7	1252.57	98.42	98.89	98.4	98.4	98.6	98.6	98.6	99.0	99.7
516131	68110.0	3553.16	93.82	94.78	93.8	94.0	94.0	94.0	94.5	95.7	97.4
516231	13671.0	642.77	94.54	95.30	94.5	94.5	94.5	94.7	95.1	96.0	98.1
516331	19940.6	412.37	97.70	97.93	97.7	97.7	97.7	97.8	98.0	98.7	99.3
516431	48153.7	363.93	98.99	99.24	99.0	99.0	99.0	99.0	99.0	99.3	99.9
Total	773696.9	11982.44		98.45							
Scenario 5.19, Non-Uniform Monthly Target Distribution, with Forecasting											
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64855.1	302.05	99.43	99.53	99.4	99.4	99.4	99.4	99.7	99.9	100.0
515731	17973.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13938.4	482.69	96.12	96.54	96.1	96.1	96.1	96.1	96.4	97.0	97.4
509431	98033.9	4877.71	88.79	95.02	88.8	89.1	89.4	90.4	98.1	99.4	100.0
516531	65345.2	974.27	98.42	98.51	98.4	98.4	98.6	98.7	98.9	98.9	99.1
515931	20036.7	816.64	96.70	95.92	96.7	96.8	97.0	97.3	97.7	98.0	98.4
516031	112552.6	2628.22	96.84	97.66	96.8	96.8	97.0	97.0	97.4	97.8	98.4
516131	68142.1	4096.48	93.25	93.99	93.2	93.2	93.2	93.4	93.8	94.8	96.6
516231	13681.2	832.90	93.53	93.91	93.5	93.5	93.5	93.5	93.7	94.3	96.3
516331	19980.5	648.94	96.84	96.75	96.8	96.8	96.8	96.8	97.0	97.6	98.1
516431	48296.8	687.12	98.71	98.58	98.7	98.7	98.7	98.7	98.9	99.0	99.1
Total	773586.0	16347.05		97.89							

Table 5.44 Mean Shortage for Selected Run-of-river Water Rights for Scenarios 5.08, 5.18, and 5.19

Selected Water Rights	Target Diversion ac-ft per year	Mean Annual Shortage, ac-ft per year		
		5.08	5.18	5.19
Dec. 31, 1929, and Senior, all uses	120,722	10,090	6,660	5,148
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	8,020	6,869	5,300
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	36,433	31,913	27,939
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	25,967	18,201	19,819
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	34,174	27,233	25,467
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,462	1,384	1,523
Jan. 1, 1980, and Junior, municipal use	75,000	16,109	15,841	17,575
Jan. 1, 1980, and Junior, non-municipal use	84,261	32,912	25,532	25,643
All Selected Water Rights	790,221	165,165	133,632	128,414

Table 5.45 Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.08, 5.18, and 5.19

Selected Water Rights	Volume Reliability, %		
	5.08	5.18	5.19
Dec. 31, 1929, and Senior, all uses	91.6	94.5	95.7
Jan. 1, 1930, to Dec. 31, 1939, all uses	89.4	90.9	93.0
Jan. 1, 1940, to Dec. 31, 1949, all uses	81.0	83.4	85.4
Jan. 1, 1950, to Dec. 31, 1959, all uses	76.9	83.8	82.3
Jan. 1, 1960, to Dec. 31, 1969, all uses	72.8	78.3	79.8
Jan. 1, 1970, to Dec. 31, 1979, all uses	68.9	70.5	67.5
Jan. 1, 1980, and Junior, municipal use	78.5	78.9	76.6
Jan. 1, 1980, and Junior, non-municipal use	60.9	69.7	69.6
All Selected Water Rights	79.1	83.1	83.7

Table 5.46 Water Balance Makeup at Selected Control Points for Scenarios 5.08, 5.18, and 5.19

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
	Scenario 5.08, Uniform Target Distribution, No Forecasting				
BRBR59	Bryan Gage	-1,190.6	-0.030	-2,356.5	-0.113
BRHE68	Hempstead Gage	-1,608.0	-0.030	-3,157.2	-0.111
BRRI70	Richmond Gage	-1,496.7	-0.026	-2,801.0	-0.089
LRCA58	Cameron Gage	-46.1	-0.003	-92.2	-0.017
BRGM73	Gulf Outlet	-691.7	-0.011	-1,233.0	-0.038
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-837.9	-0.077	-1,136.2	-0.195
515731	Whitney Lake	-544.6	-0.040	-368.3	-0.049
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.6	0.000	-0.3	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-50.6	-0.010	-99.6	-0.052
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.4	0.000	-0.8	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000
	Scenario 5.18, Non-Uniform Monthly Target Distribution, No Forecasting				
BRBR59	Bryan Gage	-1,176.1	-0.029	-2,326.1	-0.112
BRHE68	Hempstead Gage	-1,454.8	-0.027	-2,759.0	-0.097
BRRI70	Richmond Gage	-1,341.0	-0.023	-2,387.4	-0.076
LRCA58	Cameron Gage	-56.1	-0.004	-110.9	-0.021
BRGM73	Gulf Outlet	-542.2	-0.009	-887.7	-0.027
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-833.1	-0.076	-1,085.9	-0.187
515731	Whitney Lake	-531.8	-0.039	-372.8	-0.049
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-0.4	0.000	-0.1	0.000
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-57.8	-0.011	-113.0	-0.059
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.5	0.000	-1.1	-0.002
516431	Somerville Lake	0.0	0.000	0.0	0.000

Table 5.46 Continued

Bwam Control Point Identifier	Control Point Location Name	Water Balance Makeup, All 58 Years		Water Balance Makeup, Driest 29 Years	
		Average Makeup, ac-ft per year	% of Naturalized Flow	Average Makeup, ac-ft per year	% of Naturalized Flow
	Scenario 5.19, Non-Uniform Monthly Target Distribution, with Forecasting				
BRBR59	Bryan Gage	-985.3	-0.024	-1,970.6	-0.095
BRHE68	Hempstead Gage	-930.4	-0.017	-1,484.8	-0.052
BRRI70	Richmond Gage	-1,067.1	-0.018	-2,134.1	-0.068
LRCA58	Cameron Gage	-944.7	-0.072	-1,889.4	-0.350
BRGM73	Gulf Outlet	-268.9	-0.004	-520.6	-0.016
515531	Possum Kingdom Lake	0.0	0.000	0.0	0.000
515631	Granbury Lake	-542.2	-0.050	-746.3	-0.128
515731	Whitney Lake	-494.8	-0.036	-213.2	-0.028
515831	Aquilla Lake	0.0	0.000	0.0	0.000
509431	Waco Lake	-2.0	-0.001	-2.1	-0.001
516531	Limestone Lake	0.0	0.000	0.0	0.000
515931	Proctor Lake	0.0	0.000	0.0	0.000
516031	Belton Lake	-2.5	0.000	-4.7	-0.002
516131	Stillhouse Lake	0.0	0.000	0.0	0.000
516231	Georgetown Lake	0.0	0.000	0.0	0.000
516331	Granger Lake	-0.3	0.000	-0.6	-0.001
516431	Somerville Lake	0.0	0.000	0.0	0.000

CHAPTER VI

FLOOD CONTROL SIMULATIONS

Flood control capabilities of SIMD, USACE flood control operating schedule for the Brazos River Basin and the development of flood control routing parameters, reservoir input records, and downstream flood flow limit records are discussed in Chapters II, III, and IV. These input data, SIMD records, and parameterizations are used in a flood control simulation study of the Brazos River Basin and San Jacinto-Brazos Coastal WAM. The final daily Bwam simulation from Chapter V, scenario 5.19, is extended to incorporate all nine USACE flood control reservoirs in the Brazos River Basin. Simulations in Chapter V only included reservoir capacity up to the top of the conservation pool. Input records for the flood control simulation are developed in Chapter IV.

The objective of Chapter VI is to examine the performance of the SIMD flood control features in reducing regulated flow below maximum allowable release rates at the flood control reservoirs and the maximum allowable discharge rates at downstream flood flow gaging locations. Flood control input records are developed for SIMD using real-world USACE flood control limits and flood control pool elevation, capacity, and area data.

Sensitivity to the length of the regulated flow forecasting period is tested for the flood control configuration in the Bwam case study. Regulated flow forecasting periods are varied in SIMD at the downstream FF record locations in the model. Simulation results are compared in terms of the effect on regulated flood flow frequency and flood storage frequency. After examination of the flood control performance with respect to forecasting period, a single set of flood control forecasting periods are selected. The selected flood control scenarios are examined versus the final daily simulation in Chapter V with respect to the effect of flood control on water availability and regulated flow frequency.

The conceptual structure of a SIMD multi-purpose conservation and flood control reservoir is shown in Figure 2.4. In SIMD, a reservoir may consist of any or all of the four pools shown in Figure 2.4. In SIM, only the inactive and conservation pools are available for modeling. In SIM and SIMD, inactive and conservation pools are defined with WS records and associated with WR records. In SIMD, controlled and uncontrolled pools are specified by FR records. The following terms are used throughout this chapter when referring to flood control operations in SIMD:

- **Flood control pool:** storage capacity defined by FR record fields 9 and 11. A flood control pool may consist of multiple controlled or a single uncontrolled storage pool.
- **Controlled flood control storage:** storage capacity that makes storage or release decisions based on maximum allowable flows at the location of the reservoir or at downstream control points specified by FF records. Controlled pools are differentiated from uncontrolled pools by setting the level of a gate, FCGATE, in field 10 of the FR record.
- **Uncontrolled flood control storage:** storage capacity that stores and releases water only with consideration of the hydraulic inflow and outflow relationship defined by the FV/FQ records. Uncontrolled

flood control pools can only be defined as the top-most pool of a reservoir in SIMD.

- **Flood flow limit gage**: control point location of an FF record. If regulated flow exceeds the FF record daily target flow requirement, all upstream controlled flood control pools will begin storing water. Additionally, controlled flood control pools will limit releases from flood control storage so as not to increase regulated flows above the FF record target flow requirement. Future regulated flows can be considered with forecasting.

The selected control points listed in Table 4.2 are used in this chapter to report simulation results. The locations of these control points are shown in Figure 4.2. The only reservoirs considered in the results are those with USACE flood control storage capacity. The six USGS stream gaging control points listed in Table 4.2 also correspond to the six flood flow discharge monitoring locations listed in Table 4.17.

6.1 Simulation Scenarios

Table 6.1 lists the simulation scenarios considered in this chapter. The forecast periods of the FF record rights are altered in this chapter to examine the effect on the simulation results with respect to reducing regulated flows below flood discharge limits as well as minimizing the likelihood of exceeding the maximum flood control capacity of the reservoir. The FF records used in the simulations are listed in Table 4.16. The FR records are listed in Table 4.15 but are not changed per simulation scenario of this chapter.

All flood control scenarios are built upon the DAT file for the daily time step simulation scenario 5.19 from Chapter V. The parameters for scenario 5.19 are given in Table 5.2. Pertinent features of scenario 5.19 include daily flow pattern disaggregation, lag and attenuation routing, forecasting for downstream senior shortages, forecasting periods assigned according to water right priority number, and non-uniform demand target distributions assigned according to the water right's type of use. No FR or FF records are included in the DAT file for scenario 5.19. Therefore, scenario 5.19 can be used as a basis of comparison for the reduction of regulated flow by the flood control features of the simulation scenarios in this chapter.

The FF record forecast periods for the simulation scenarios in Table 6.1 are varied according to the distance to the upstream flood control reservoirs. The forecasting periods at the FF record nearer to the flood control reservoirs are shorter than those FF records farther from the flood control reservoirs to reflect relative travel times between the flood control reservoirs and the stream gages where the FF record rights are located.

Table 6.1 Regulated Flow Forecasting Periods per Chapter VI Simulation Scenario

Scenario ID	FF Record Forecasting Period for Regulated Flow, days					
	Gages Farther from the Flood Control Reservoirs			Gages Nearer to the Flood Control Reservoirs		
	Brazos River at Bryan, BRBR59	Brazos River at Richmond, BRRI70	Little River at Cameron, LRCA58	Brazos River at Waco, BRWA41	Leon River at Gatesville, LEGT47	Little River at Little River, LRLR53
5.19	na	na	na	na	na	na
6.01	0	0	0	0	0	0
6.02	1	1	1	0	0	0
6.03	3	3	3	0	0	0
6.04	5	5	5	0	0	0
6.05	7	7	7	0	0	0
6.06	1	1	1	1	1	1
6.07	3	3	3	1	1	1
6.08	5	5	5	1	1	1
6.09	7	7	7	1	1	1
6.10	3	3	3	2	2	2
6.11	5	5	5	2	2	2
6.12	7	7	7	2	2	2

6.2 Forecasting Period and Flood Wave Propagation

Daily naturalized flows at the location of Whitney Lake and the three downstream gage locations of the FF record rights are shown in Figure 6.1 for a major flood event. The maximum allowable discharge at Whitney Lake is 49,588 ac-ft per day. The maximum allowable discharge set by the three downstream FF record rights is 119,010 ac-ft per day. Naturalized flow at Whitney Lake exceeds 49,588 ac-ft per day, and the hydrograph peaks between December 20 and 21. Peak flow is reached at the Waco gage between December 21 and 22. Peak flow is reached at the Bryan gage between December 23 and 24. Peak flow is reached at the Richmond gage between December 25 and 26.

When flow exceeds the discharge limit at Whitney Lake, the flood control reservoir will begin impounding all flow at the location of Whitney Lake. The decision to begin impounding based on the discharge limit at the dam site may occur several days prior to flow exceeding discharge limits at the downstream gages of the FF record rights. Therefore, increasing forecast periods for downstream FF record rights may not always result in a decision to begin impounding earlier in the flood event by the controlled flood control pool. During flood events such as the one shown in Figure 6.1, flood conditions at the dam site will trigger the decision to begin impounding flood waters several days prior to the onset of flood conditions at the downstream gages. However, forecast periods at the downstream locations of the FF record rights may extend protection to downstream locations in future time steps when upstream flood control releases are being made.

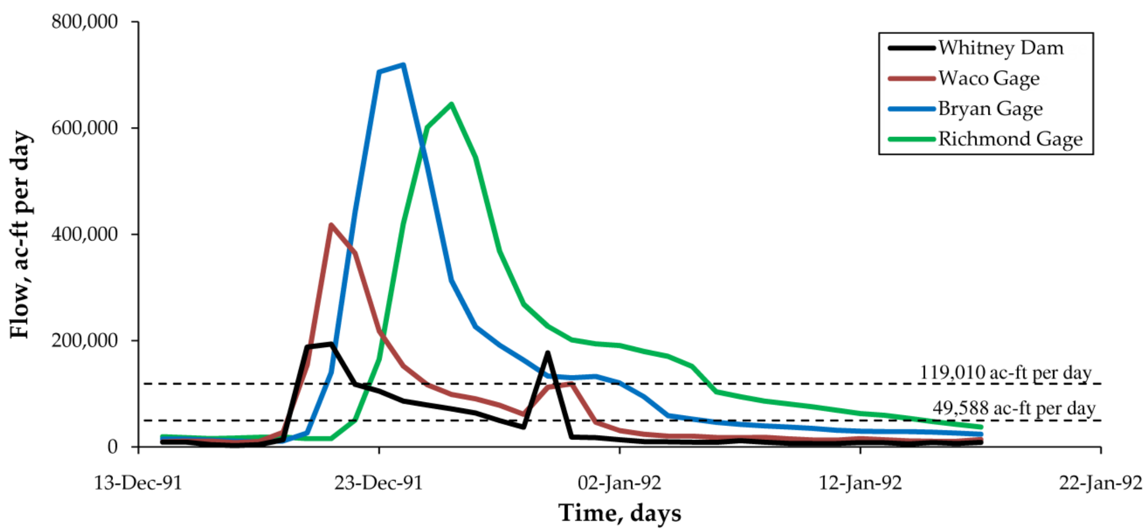

Figure 6.1 Daily Disaggregated Naturalized Flows along the Main Stem Brazos River during the Flood Event of December 1991

6.3 Simulation Results

The results of the simulations are compiled in tables showing the number of days of exceedance during the simulation. The period of record from January 1, 1940, through December 31, 1997, covers 21,185 days. The numbers of days identified in the tables of simulation results are small relative to the overall number of days in the simulation, and the differences in the number of days between simulations are even smaller. Therefore, the compiled results are not presented in a decimal frequency percentage format. Instead, results of exceedance are presented in a count format so the exact number of days can be compared between simulation scenarios.

The number of days when regulated flow equals or exceeds the maximum discharge or release rates at the downstream flood gages or at the flood control dam sites, respectively, is listed in Tables 6.2 and 6.3. The exceedance of the maximum discharge and release rates for the daily naturalized flow inputs are given in the first line of Tables 6.2 and 6.3 for comparison purposes. Comparing scenario 5.19 and the Chapter VI scenarios illustrates that including flood control in the simulation significantly reduces the incidence of flood flow exceedance at the downstream gages and at the dam sites. Increasing the forecasting period of the FF record rights in the Chapter VI scenarios reduces the number of days of regulated flow exceedance at the downstream gages, with the exception of the Little River gage. However, increasing the forecast period does not reduce the number of days of flood flow exceedance at the dam sites for the Chapter VI scenarios, as shown in Table 6.3. Over-forecasting for downstream flow conditions can result in increased flood control pool content, which in turn diminishes the ability of the flood control pool to reduce the regulated flow at the dam site below the dam's maximum release rate. Tables 6.4 and 6.5 show that forecasting increases the number of days in which the reservoirs are completely full during the simulation.

Scenario 6.10 applies 3 days of regulated flow forecasting at the Bryan, Richmond, and Cameron gages and 2 days of regulated flow forecasting at the Waco, Gatesville, and Little River gages. The results presented in Table 6.2 through Table 6.5 indicate that these forecasting periods approach a balance between reducing the incidence of downstream flood flow exceedance and flood control capacity exceedance. Other combinations of forecasting periods may exist that minimize either downstream flow exceedance or flood control capacity exceedance. Scenarios 5.19, 6.01, and 6.10 will be examined further for the effect of adding flood control to the daily Bwam simulation and for the effect of adding a forecasting period to the FF record rights. Results will be presented for the selected control points listed in Table 4.2.

Table 6.2 Number of Days in the Simulation When Regulated Flow Equals or Exceeds the Maximum Allowable Discharge at FF Record Gages

	Brazos River at Waco, BRWA41	Brazos River at Bryan, BRBR59	Brazos River at Richmond, BRRI70	Leon River at Gatesville, LEGT47	Little River at Little River, LRLR53	Little River at Cameron, LRCA58
Naturalized Flow	53	198	307	233	382	721
5.19	33	151	232	206	263	581
6.01	2	39	92	110	23	242
6.02	2	33	79	110	28	221
6.03	2	26	51	109	31	206
6.04	2	28	47	109	33	211
6.05	2	29	52	111	33	212
6.06	2	34	78	106	27	218
6.07	2	26	50	107	31	209
6.08	2	28	47	107	33	210
6.09	2	29	53	108	33	212
6.10	2	26	51	107	31	209
6.11	2	28	48	107	33	211
6.12	2	29	52	108	33	209

Table 6.3 Number of Days in the Simulation When Regulated Flow Equals or Exceeds the Maximum Release at FR Record Flood Control Reservoirs

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
Naturalized Flow	210	158	9	184	188	41	41	82	586
5.19	137	125	8	136	125	29	34	73	483
6.01	5	0	0	4	4	2	0	4	1
6.02	6	0	0	4	4	2	0	4	2
6.03	7	0	0	8	8	2	0	4	2
6.04	11	0	0	8	10	3	1	5	3
6.05	12	0	0	10	11	3	1	6	4
6.06	6	0	0	5	4	2	0	4	2
6.07	7	0	0	8	8	2	0	4	2
6.08	11	0	0	8	10	3	1	5	3
6.09	13	0	0	10	11	3	1	6	4
6.10	7	0	0	8	8	2	0	4	2
6.11	11	0	0	8	10	3	1	5	3
6.12	12	0	0	10	11	3	1	6	4

Table 6.4 Number of Days in the Simulation When Storage Contents Equals or Exceeds the Top of Conservation Storage Capacity

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
5.19	1,553	826	288	2,119	4,100	3,633	3,372	6,185	4,352
6.01	2,505	2,722	1,205	4,810	5,493	5,084	5,419	7,248	5,321
6.02	2,500	2,738	1,239	4,823	5,512	5,131	5,434	7,273	5,323
6.03	2,456	2,697	1,263	4,847	5,537	5,174	5,425	7,344	5,315
6.04	2,371	2,689	1,332	4,883	5,617	5,209	5,488	7,435	5,318
6.05	2,380	2,734	1,341	4,904	5,672	5,295	5,474	7,467	5,299
6.06	2,466	2,748	1,236	4,829	5,514	5,128	5,423	7,294	5,324
6.07	2,433	2,699	1,262	4,855	5,552	5,159	5,436	7,337	5,319
6.08	2,397	2,726	1,331	4,889	5,596	5,214	5,475	7,405	5,319
6.09	2,363	2,732	1,358	4,919	5,638	5,279	5,484	7,440	5,302
6.10	2,490	2,726	1,266	4,881	5,555	5,204	5,446	7,305	5,318
6.11	2,387	2,724	1,328	4,900	5,632	5,249	5,460	7,401	5,307
6.12	2,379	2,738	1,348	4,925	5,667	5,284	5,465	7,395	5,299

Table 6.5 Number of Days in the Simulation When Storage Contents Equals or Exceeds the Top of Flood Control Capacity

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
5.19	na	na	na	na	na	na	na	na	na
6.01	7	0	0	15	33	33	0	54	2
6.02	7	0	0	21	48	39	5	59	4
6.03	15	0	29	38	50	48	4	59	5
6.04	20	0	34	44	54	51	13	59	5
6.05	23	0	36	45	55	53	21	59	6
6.06	6	0	0	22	48	38	4	59	4
6.07	14	0	29	38	50	48	4	59	5
6.08	20	0	34	44	54	51	13	59	5
6.09	24	0	36	45	55	53	20	59	6
6.10	14	0	32	38	50	48	4	59	5
6.11	20	0	34	44	54	51	13	59	5
6.12	23	0	36	45	55	53	21	59	6

6.3.1 Peak Annual Flow and Streamflow

SIMD reports the peak annual naturalized and regulated flow and peak annual reservoir storage for selected control points in the AFF output file. TABLES uses the log-Pearson type III probability distribution to analyze data from the AFF file. Peak annual naturalized and regulated flow-frequencies are provided in Tables 6.6 and 6.8 at the selected control points. Statistics for the statistical fit are provided in Tables 6.7 and 6.9.

Peak annual flow is reduced across all exceedance frequencies in Table 6.8 when flood control is included in the Bwam simulation. In particular, the maximum value of regulated flow during the simulation is greatly reduced with the inclusion of flood control. The maximum value of regulated flow is presented in the table statistics. With the addition of forecasting for downstream regulated flow, as seen in the comparison of scenario 6.01 and 6.10, the peak annual flows are reduced at all locations except for the Gatesville gage and the dam sites of Proctor, Granger, and Somerville. The increase in peak annual flows at these locations is a result of the increase in the number of days in which storage contents equals or exceeds the top of flood control capacity.

When the flood control pool is completely full, there is no capacity available for mitigating flooding conditions. In scenario 6.01, the flood control pool at Somerville Lake is completely full for 2 days during the simulation. In scenario 6.10, the flood control pool at Somerville Lake is completely full for 5 days. The maximum regulated flow at the dam site of Somerville Lake increases from 5,083 to 10,033 ac-ft per day between scenarios 6.01 and 6.10, respectively.

Table 6.6 Peak Annual Flow Frequency for Daily Naturalized Streamflow, ac-ft per day

CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
BRWA41	12691.	74527.	134428.	181086.	246893.	300369.	357299.	417853.	503679.	94479.
BRBR59	22028.	118974.	214600.	290889.	401093.	492768.	592335.	700351.	856972.	152371.
BRRI70	20820.	124016.	222844.	299039.	405488.	491211.	581781.	677406.	811803.	156185.
LEGT47	613.	12918.	27916.	39222.	53927.	64742.	75210.	85280.	97927.	18353.
LRLR53	2338.	30857.	69973.	104879.	158725.	205528.	257724.	315447.	400442.	49186.
LRCA58	4799.	49760.	102526.	145942.	208828.	260653.	316127.	375206.	458736.	70776.
515731	11046.	53226.	91951.	121810.	163851.	198076.	234641.	273716.	329468.	65454.
515831	909.	10139.	19691.	26751.	36023.	42991.	49905.	56747.	65653.	13227.
509431	1758.	23661.	52375.	77057.	113842.	144808.	178441.	214694.	266556.	36281.
515931	626.	12246.	30170.	46680.	72471.	94978.	120053.	147674.	188055.	21235.
516031	1531.	23705.	52793.	77257.	112799.	141938.	172855.	205405.	250702.	36122.
516131	559.	13421.	34137.	53268.	82963.	108615.	136886.	167656.	211963.	23917.
516231	122.	4161.	10296.	15402.	22510.	28025.	33569.	39082.	46242.	6856.
516331	469.	11062.	24667.	35163.	49031.	59357.	69441.	79216.	91588.	16243.
516431	607.	12357.	30354.	46740.	72025.	93823.	117853.	144048.	181883.	21228.

Table 6.7 Log-Pearson Type III Distribution Frequency Statistics for Daily Naturalized Streamflow

CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	Statistics for Logarithms of Annual Peaks: MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	93209.	69353.	10551.	417598.	4.8642	0.3117	-0.2000	-0.1428	-0.1569
BRBR59	150573.	117164.	25997.	719015.	5.0722	0.3073	-0.2000	-0.0229	-0.0639
BRRI70	154086.	112704.	24380.	645001.	5.0839	0.3110	-0.2000	-0.1801	-0.1851
LEGT47	17411.	16771.	459.	92376.	4.0594	0.4511	-0.2000	-0.9886	-0.6941
LRLR53	46594.	47333.	2360.	207259.	4.4710	0.4393	-0.2000	-0.2695	-0.2514
LRCA58	67982.	58911.	4635.	289749.	4.6772	0.3913	-0.2000	-0.3400	-0.3022
515731	64857.	42818.	9562.	193612.	4.7226	0.2853	-0.2000	-0.0372	-0.0751
515831	12789.	9663.	578.	44240.	3.9731	0.3750	-0.2000	-0.6795	-0.5287
509431	34593.	35649.	1284.	219455.	4.3508	0.4318	-0.2000	-0.3705	-0.3239
515931	20202.	27943.	418.	200316.	4.0602	0.4913	-0.2000	-0.3929	-0.3396
516031	34423.	34593.	1556.	165626.	4.3446	0.4420	-0.2000	-0.4980	-0.4116
516131	22415.	27011.	397.	120489.	4.0934	0.5143	-0.2000	-0.4840	-0.4022
516231	6276.	6355.	73.	26837.	3.5610	0.5271	-0.2000	-0.9269	-0.6674
516331	15147.	13497.	253.	61175.	3.9905	0.4687	-0.2000	-0.9731	-0.6876
516431	19214.	18453.	1233.	98735.	4.0615	0.4925	-0.2000	-0.4389	-0.3715

Table 6.8 Peak Annual Flow Frequency for Daily Regulated Streamflow for Scenarios 5.19, 6.01, and 6.10, ac-ft per day

CONTROL		ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)								EXPECTED
	1.01	2	5	10	25	50	100	200	500	
POINT	99%	50%	20%	10%	4%	2%	1%	0.5%	0.2%	VALUE
Scenario 5.19, without Flood Control										
BRWA41	6429.	58507.	117498.	165724.	235535.	293175.	355057.	421207.	515212.	81445.
BRBR59	15155.	98865.	187137.	259062.	364202.	452328.	548452.	653028.	804954.	131889.
BRRI70	10722.	104558.	202515.	277036.	377973.	456239.	536001.	617057.	725844.	137638.
LEGT47	455.	11191.	25788.	37499.	53494.	65765.	78035.	90196.	105969.	17135.
LRLR53	1181.	21004.	55805.	91780.	154491.	215120.	288713.	376835.	518484.	41989.
LRCA58	3658.	42013.	91494.	134531.	199768.	255713.	317513.	385299.	484292.	64015.
515731	4011.	40411.	79341.	109341.	150382.	182478.	215402.	249064.	294535.	53976.
515831	378.	8289.	18897.	27476.	39334.	48552.	57881.	67242.	79557.	12629.
509431	269.	18867.	52790.	82202.	123377.	155024.	186347.	216865.	255424.	35073.
515931	282.	6643.	20346.	36347.	67237.	99846.	142308.	196612.	290494.	16729.
516031	546.	15925.	43532.	70552.	114423.	153779.	198427.	248328.	322261.	31271.
516131	309.	9199.	27052.	46121.	79667.	112043.	151057.	197269.	270363.	20547.
516231	30.	2701.	8579.	14348.	23301.	30837.	38849.	47198.	58548.	6018.
516331	252.	8255.	21635.	33775.	52082.	67390.	83764.	101043.	125032.	14917.
516431	96.	8425.	29171.	51869.	90869.	126926.	168355.	214856.	283561.	21988.
Scenario 6.01, with Flood Control but without Flood Gage Forecasting										
BRWA41	7180.	44409.	73747.	93328.	117434.	134694.	151266.	167225.	187463.	50729.
BRBR59	15244.	79088.	130944.	167334.	214440.	249894.	285407.	321067.	368503.	91667.
BRRI70	10520.	87120.	151783.	194892.	247253.	284051.	318734.	351465.	391962.	102310.
LEGT47	433.	9411.	21026.	30165.	42497.	51874.	61197.	70395.	82272.	13950.
LRLR53	1604.	9336.	18259.	26118.	38474.	49567.	62384.	77134.	99982.	13239.
LRCA58	2760.	28656.	57096.	79344.	110148.	134492.	159669.	185607.	220935.	38912.
515731	4722.	33705.	54600.	67312.	81660.	91102.	99551.	107146.	116054.	37013.
515831	641.	4606.	7194.	8651.	10186.	11133.	11936.	12622.	13382.	4872.
509431	317.	10437.	23790.	33730.	46266.	55138.	63417.	71083.	80278.	15377.
515931	212.	1879.	4933.	8499.	15653.	23624.	34607.	49561.	77556.	4172.
516031	785.	6602.	12256.	16435.	21986.	26227.	30502.	34807.	40532.	8353.
516131	389.	4314.	8319.	11250.	15067.	17914.	20721.	23482.	27052.	5580.
516231	34.	863.	2715.	4914.	9217.	13806.	19828.	27582.	41085.	2264.
516331	243.	2762.	6057.	8955.	13397.	17246.	21532.	26272.	33257.	4257.
516431	313.	2282.	4093.	5409.	7139.	8452.	9772.	11097.	12856.	2806.
Scenario 6.10, with Flood Control and with up to 3 Days Flood Gage Forecasting										
BRWA41	7299.	43510.	71229.	89462.	111659.	127399.	142401.	156748.	174808.	49098.
BRBR59	15593.	76916.	124508.	157120.	198554.	229235.	259580.	289691.	329233.	87390.
BRRI70	10699.	84965.	145592.	185308.	232905.	265970.	296858.	325773.	361236.	98279.
LEGT47	433.	9364.	20985.	30177.	42640.	52160.	61660.	71065.	83257.	13944.
LRLR53	1599.	9315.	18184.	25971.	38182.	49117.	61725.	76205.	98585.	13171.
LRCA58	2786.	27972.	55589.	77287.	107489.	131492.	156441.	182276.	217677.	37983.
515731	4723.	33650.	54501.	67189.	81515.	90945.	99386.	106977.	115883.	36952.
515831	641.	4601.	7184.	8638.	10171.	11116.	11918.	12603.	13362.	4866.
509431	322.	10403.	23388.	32894.	44716.	52978.	60614.	67618.	75937.	15073.
515931	207.	1932.	5170.	8997.	16748.	25453.	37519.	54040.	85152.	4416.
516031	809.	6359.	11584.	15398.	20422.	24235.	28063.	31903.	36990.	7911.
516131	378.	4234.	8153.	11007.	14705.	17450.	20145.	22785.	26184.	5462.
516231	31.	964.	3000.	5317.	9636.	14027.	19551.	26371.	37674.	2394.
516331	236.	2893.	6500.	9729.	14736.	19117.	24031.	29499.	37611.	4586.
516431	310.	2337.	4300.	5774.	7766.	9316.	10905.	12532.	14738.	2956.

Table 6.9 Log-Pearson Type III Distribution Frequency Statistics for Daily Regulated Streamflow for Scenarios 5.19, 6.01, and 6.10

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
				Scenario 5.19, without Flood Control					
BRWA41	78748.	68322.	5954.	412903.	4.7509	0.3748	-0.2000	-0.2826	-0.2609
BRBR59	129326.	109763.	17239.	710390.	4.9885	0.3351	-0.2000	-0.0904	-0.1166
BRRI70	133610.	106373.	7720.	635264.	4.9935	0.3659	-0.2000	-0.5180	-0.4250
LEGT47	16096.	16756.	370.	91830.	3.9981	0.4823	-0.2000	-0.8598	-0.6355
LRLR53	38106.	44697.	1480.	192764.	4.3120	0.5135	-0.2000	-0.0962	-0.1211
LRCA58	60678.	56098.	3662.	287952.	4.6066	0.4169	-0.2000	-0.2568	-0.2421
515731	52058.	39788.	4130.	187471.	4.5809	0.3725	-0.2000	-0.5001	-0.4130
515831	11512.	9276.	578.	37728.	3.8725	0.4712	-0.2000	-0.7788	-0.5887
509431	30996.	36466.	57.	219360.	4.1967	0.6142	-0.2000	-1.2396	-0.7792
515931	15291.	27562.	310.	195753.	3.8186	0.5810	-0.2000	0.0087	-0.0393
516031	28185.	33390.	562.	164449.	4.1679	0.5512	-0.2000	-0.4407	-0.3727
516131	18487.	24884.	275.	120467.	3.9399	0.5784	-0.2000	-0.2651	-0.2482
516231	5003.	5543.	24.	23855.	3.3577	0.6720	-0.2000	-0.9197	-0.6641
516331	13194.	12914.	253.	58765.	3.8696	0.5437	-0.2000	-0.6702	-0.5229
516431	17020.	18314.	254.	97764.	3.8659	0.6996	-0.2000	-0.6558	-0.5139
				Scenario 6.01, with Flood Control but without Flood Gage Forecasting					
BRWA41	50425.	27677.	8545.	131024.	4.6235	0.2853	-0.2000	-0.6442	-0.5067
BRBR59	91678.	56810.	17229.	344247.	4.8835	0.2738	-0.2000	-0.3652	-0.3201
BRRI70	100810.	62301.	6980.	282433.	4.9072	0.3197	-0.2000	-0.8338	-0.6207
LEGT47	13190.	13431.	370.	76784.	3.9251	0.4640	-0.2000	-0.8529	-0.6316
LRLR53	13049.	13379.	1480.	80653.	3.9757	0.3418	-0.2000	0.1977	0.0975
LRCA58	37155.	27092.	3592.	105684.	4.4322	0.3794	-0.2000	-0.4752	-0.3962
515731	36931.	20663.	4129.	140841.	4.4921	0.2862	-0.2000	-1.1472	-0.7523
515831	4798.	1797.	578.	5950.	3.6222	0.2750	-0.2000	-1.9478	-0.9104
509431	14190.	13068.	57.	59505.	3.9504	0.4980	-0.2000	-1.5134	-0.8309
515931	3837.	5574.	310.	38207.	3.3034	0.4762	-0.2000	0.6246	0.3715
516031	8221.	6649.	562.	44176.	3.7956	0.3423	-0.2000	-0.5149	-0.4229
516131	5395.	4063.	275.	23134.	3.6013	0.3722	-0.2000	-0.7053	-0.5445
516231	1914.	2213.	31.	5950.	2.9318	0.5951	-0.2000	0.0035	-0.0432
516331	3975.	3379.	253.	18748.	3.4262	0.4187	-0.2000	-0.2226	-0.2169
516431	2745.	1708.	380.	5083.	3.3370	0.3217	-0.2000	-0.4801	-0.3995
				Scenario 6.10, with Flood Control and with up to 3 Days Flood Gage Forecasting					
BRWA41	48960.	26364.	8507.	130925.	4.6145	0.2781	-0.2000	-0.6694	-0.5224
BRBR59	87794.	52922.	17229.	336150.	4.8708	0.2629	-0.2000	-0.4060	-0.3487
BRRI70	97212.	58968.	6980.	278199.	4.8962	0.3115	-0.2000	-0.8690	-0.6407
LEGT47	13183.	13449.	370.	76479.	3.9236	0.4647	-0.2000	-0.8354	-0.6216
LRLR53	12985.	13285.	1480.	80039.	3.9744	0.3411	-0.2000	0.1883	0.0909
LRCA58	36340.	26759.	3592.	104598.	4.4232	0.3766	-0.2000	-0.4446	-0.3754
515731	36876.	20659.	4127.	140824.	4.4915	0.2860	-0.2000	-1.1437	-0.7512
515831	4793.	1796.	578.	5950.	3.6217	0.2749	-0.2000	-1.9448	-0.9100
509431	13806.	11932.	57.	44990.	3.9480	0.4924	-0.2000	-1.6040	-0.8525
515931	4054.	6016.	310.	39761.	3.3156	0.4860	-0.2000	0.6129	0.3647
516031	7840.	6502.	562.	45309.	3.7802	0.3317	-0.2000	-0.5116	-0.4207
516131	5268.	3880.	275.	23128.	3.5924	0.3723	-0.2000	-0.7267	-0.5576
516231	2012.	2174.	31.	5950.	2.9676	0.6006	-0.2000	-0.1546	-0.1658
516331	4268.	3944.	253.	24688.	3.4457	0.4319	-0.2000	-0.2239	-0.2178
516431	2883.	1951.	380.	10033.	3.3493	0.3329	-0.2000	-0.4053	-0.3482

6.3.2 Daily Regulated Flow and Storage Contents

Time series of daily regulated flows and end-of-day reservoir storages are shown for scenarios 5.19 and 6.10 to compare the results without flood control and the results with flood control using regulated flow forecasting. The time series of regulated flows are shown in Figure 6.2 through Figure 6.16. Storages are shown in Figure 6.17 through Figure 6.25. The dashed lines accompanying the regulated flow figures are set at the maximum allowable discharges at the downstream gages and the maximum allowable releases at the dam sites. These maximum values are summarized in Table 4.17 and Table 4.18. The flood control reservoirs, however, are coded with multiple FR records to reflect variable release rate limits as a function of the current state of the storage contents in the flood pool. Likewise, the FF record for the Little River gage is coded with a drought index DI/IS/IP record set. The FF record for the Little River gage has a variable regulated flow threshold as a function of the current state of the combined storage in Proctor, Belton, and Stillhouse Hollow.

Regulated flows at the dams are reduced below the maximum release rate set by the USACE. Only when the flood control pool is completely full does regulated flow exceed the maximum rate at the dam. Downstream of the dam, regulated flows are substantially reduced during peak flow events. However, inflows from the uncontrolled drainage area below the dams at times will cause regulated flows to exceed the maximum discharge limit. The likelihood of flood causing inflows from unregulated drainage areas increases with distance away from the dams.

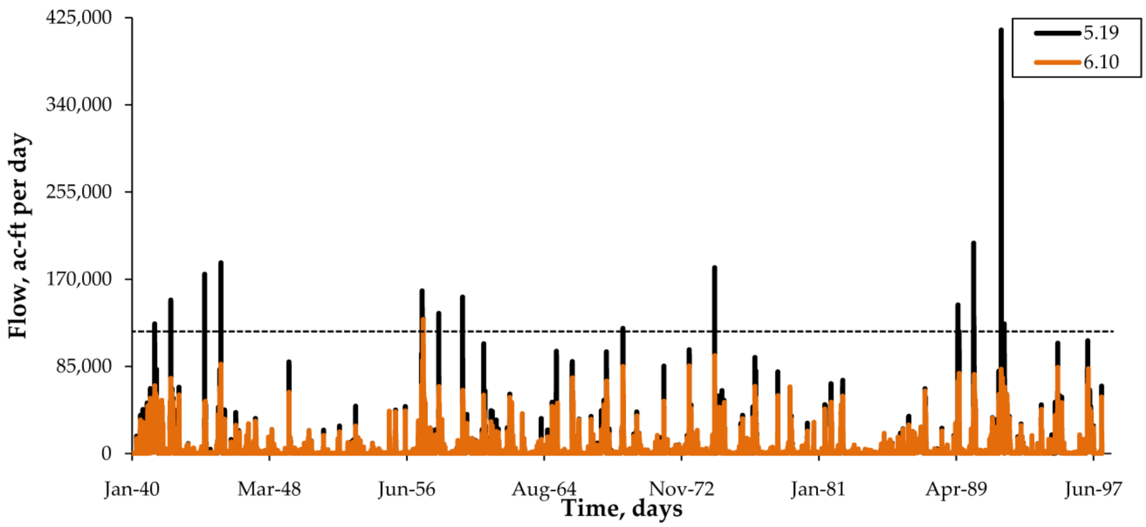

Figure 6.2 Regulated Flow at the Waco Gage on the Brazos River, BRWA41

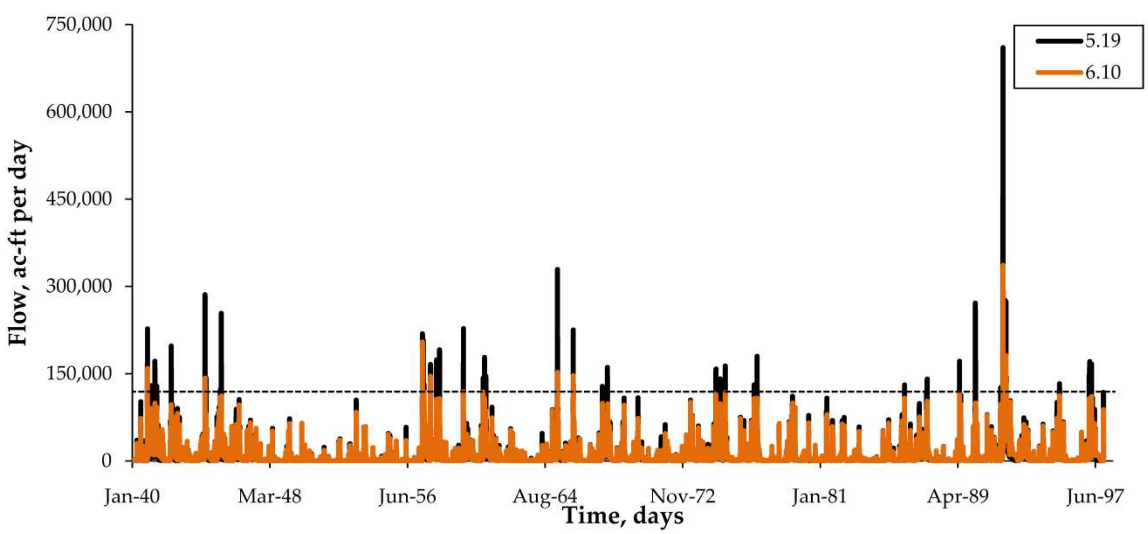

Figure 6.3 Regulated Flow at the Bryan Gage on the Brazos River, BRBR59

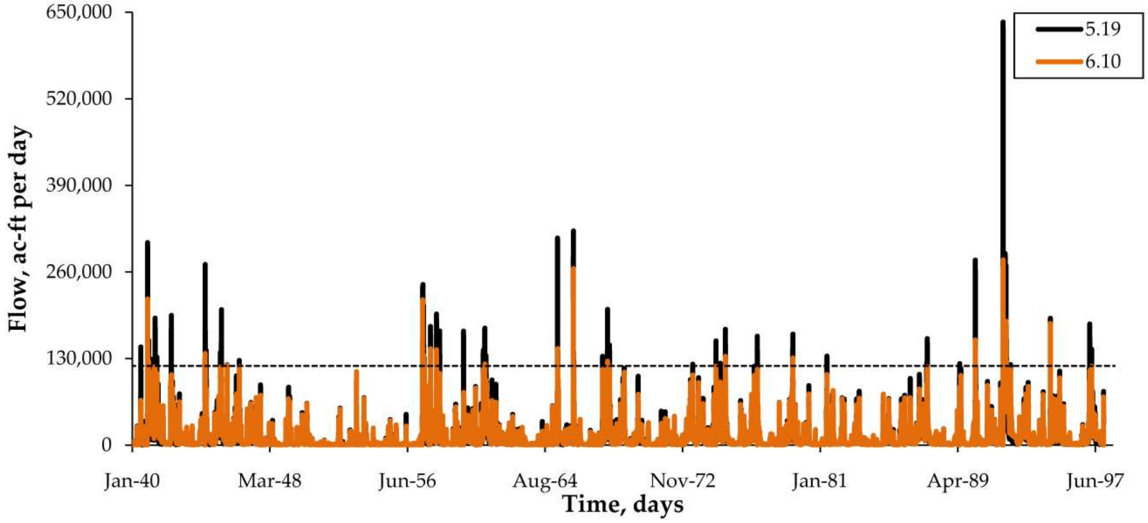

Figure 6.4 Regulated Flow at the Richmond Gage on the Brazos River, BRRI70

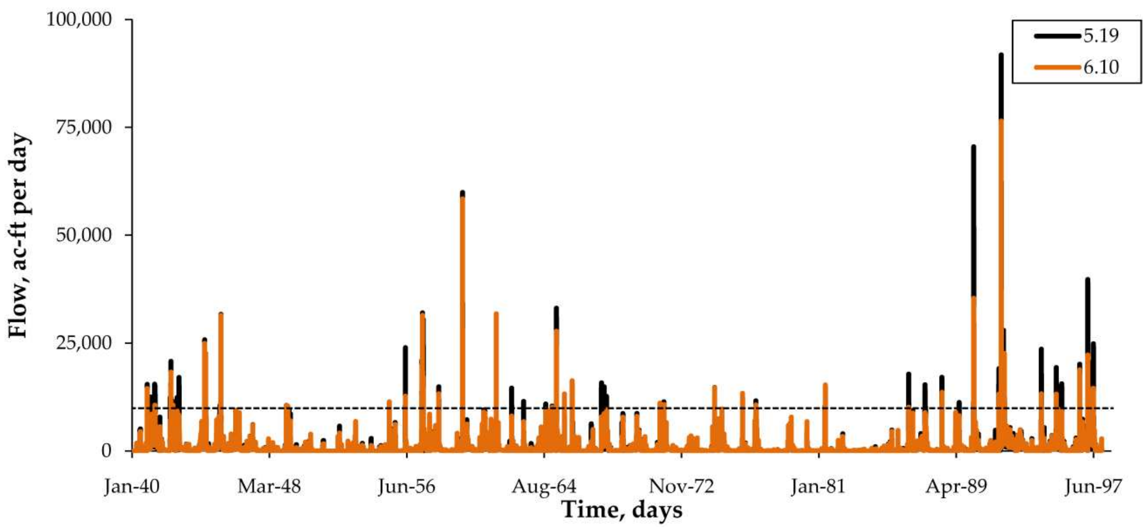

Figure 6.5 Regulated Flow at the Gatesville Gage on the Leon River, LEGT47

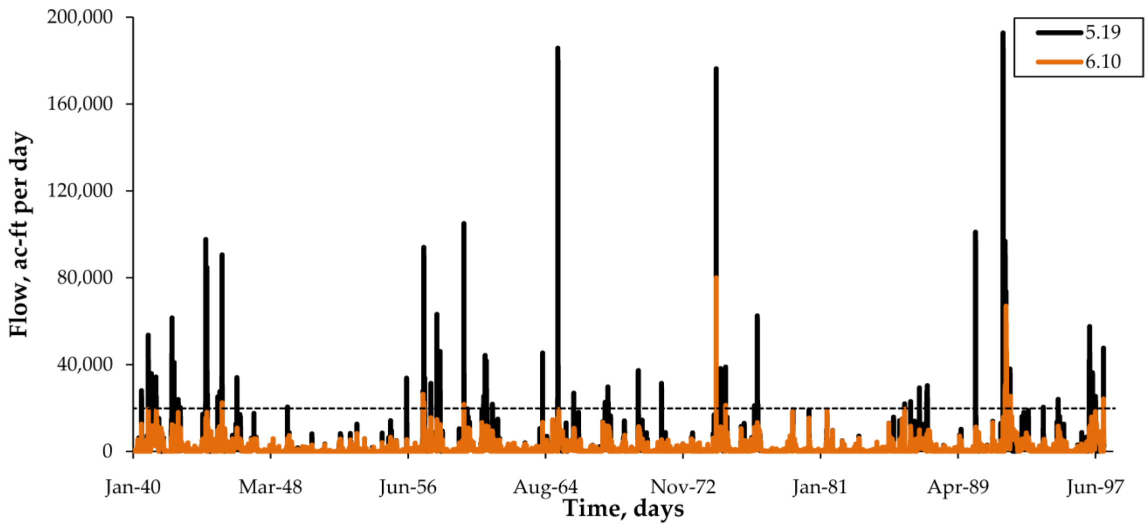

Figure 6.6 Regulated Flow at the Little River Gage on the Little River, LRLR53

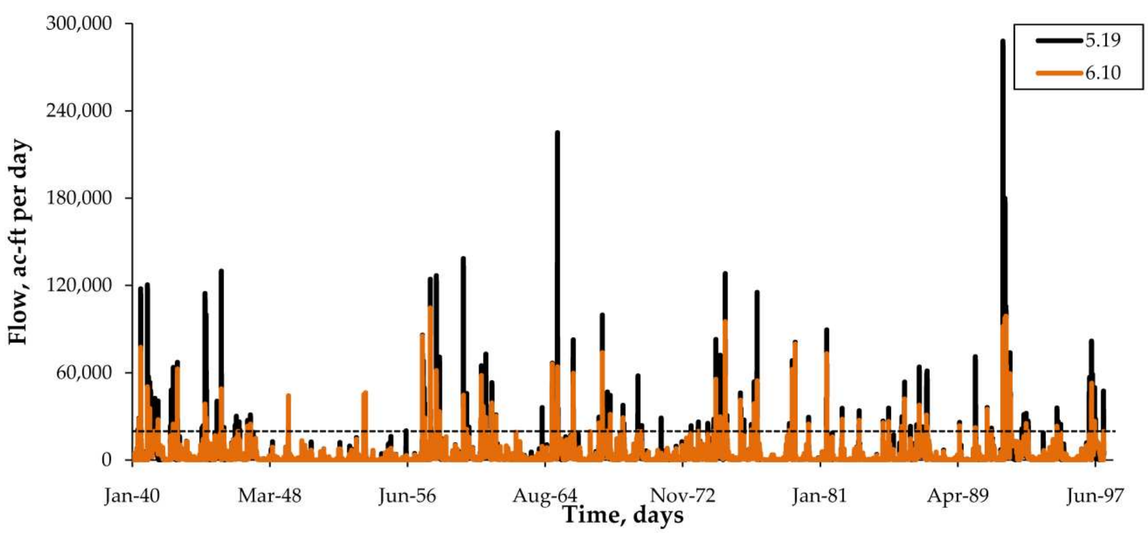

Figure 6.7 Regulated Flow at the Cameron Gage on the Little River, LRCA58

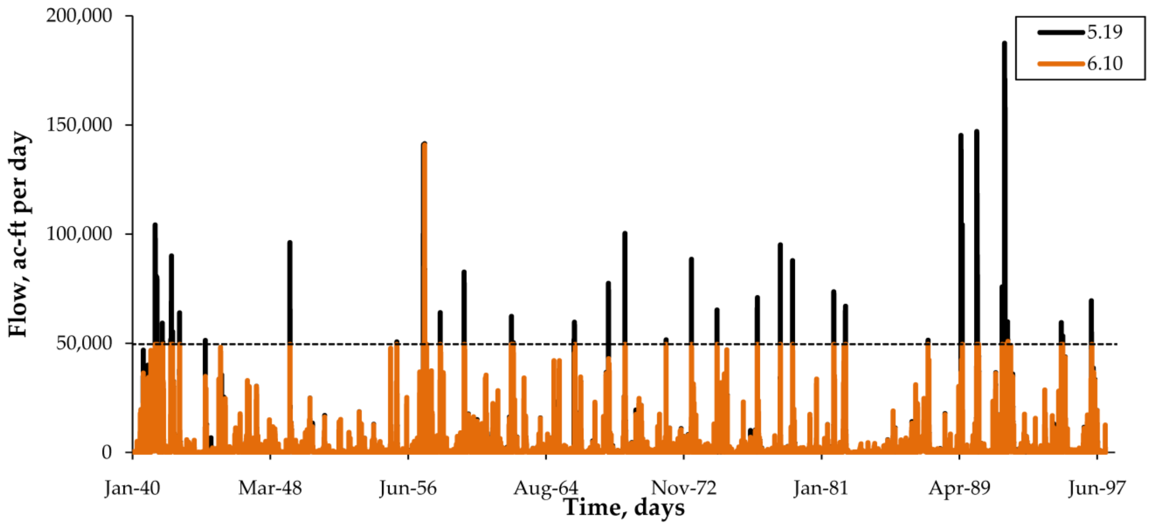

Figure 6.8 Regulated Flow at the Dam of Whitney Lake, 515731

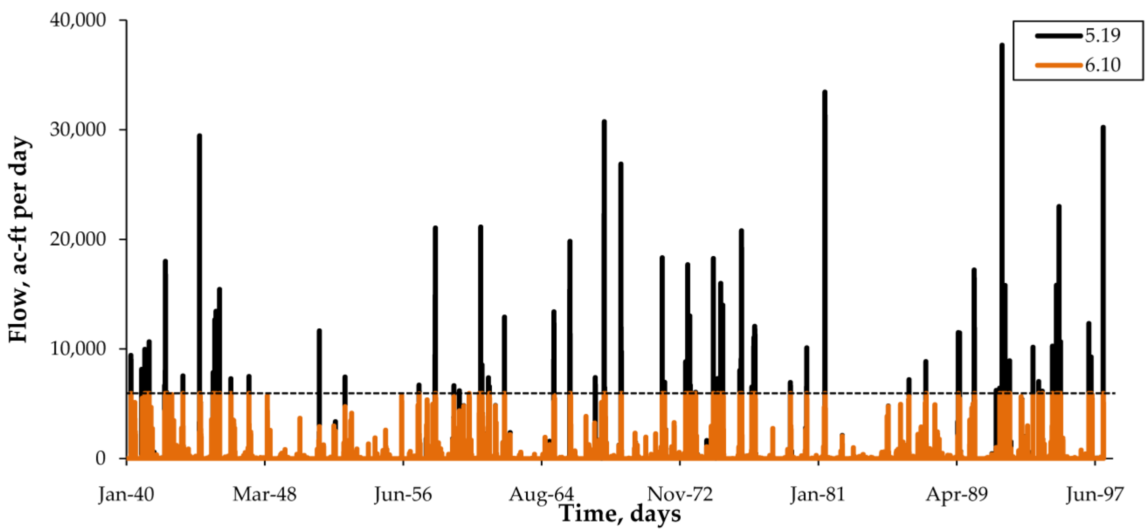

Figure 6.9 Regulated Flow at the Dam of Aquilla Lake, 515831

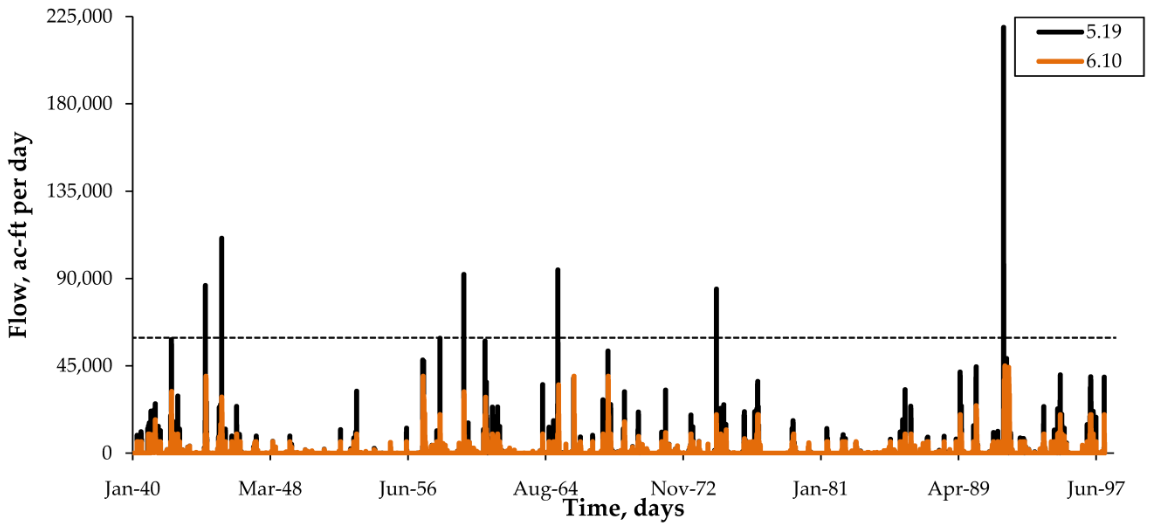

Figure 6.10 Regulated Flow at the Dam of Waco Lake, 509431

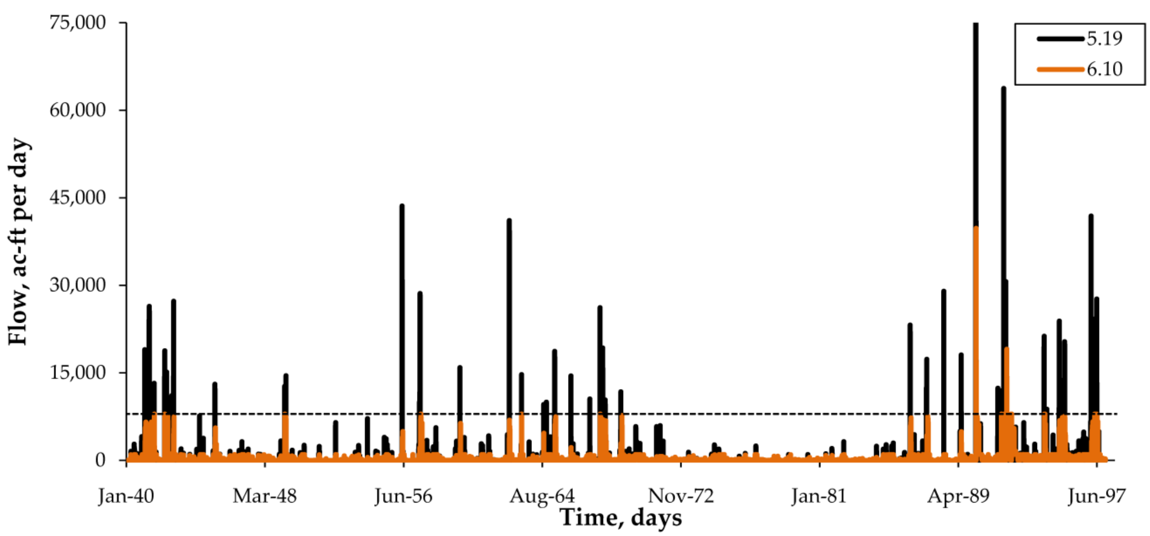

Figure 6.11 Regulated Flow at the Dam of Proctor Lake, 515931

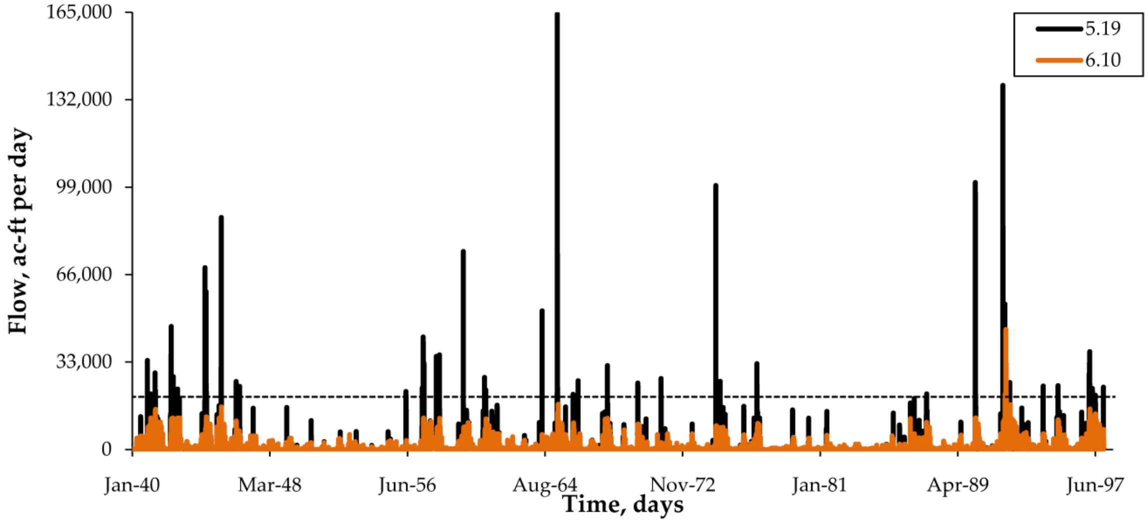

Figure 6.12 Regulated Flow at the Dam of Belton Lake, 516031

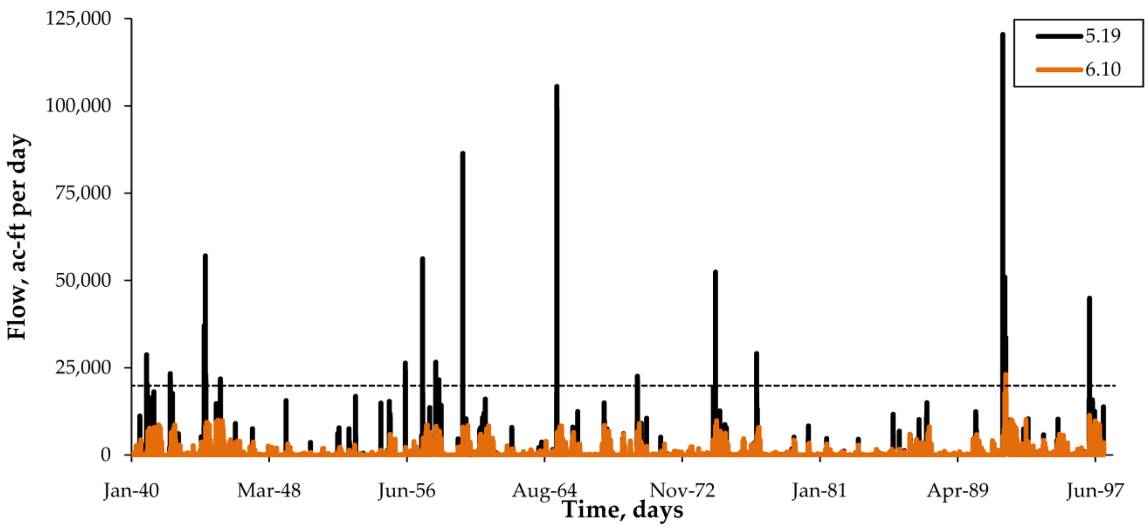

Figure 6.13 Regulated Flow at the Dam of Stillhouse Hollow Lake, 516131

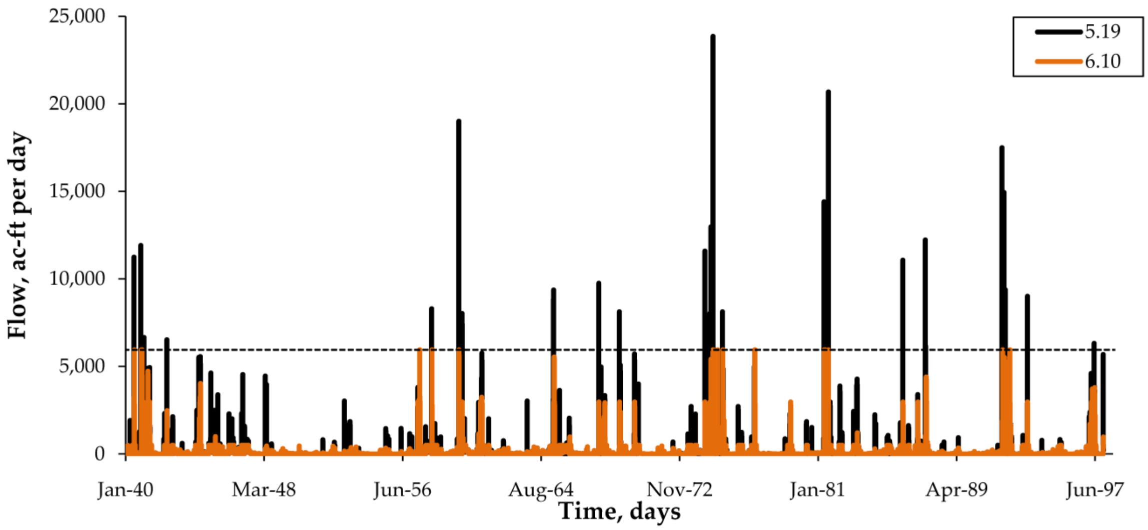

Figure 6.14 Regulated Flow at the Dam of Georgetown Lake, 516231

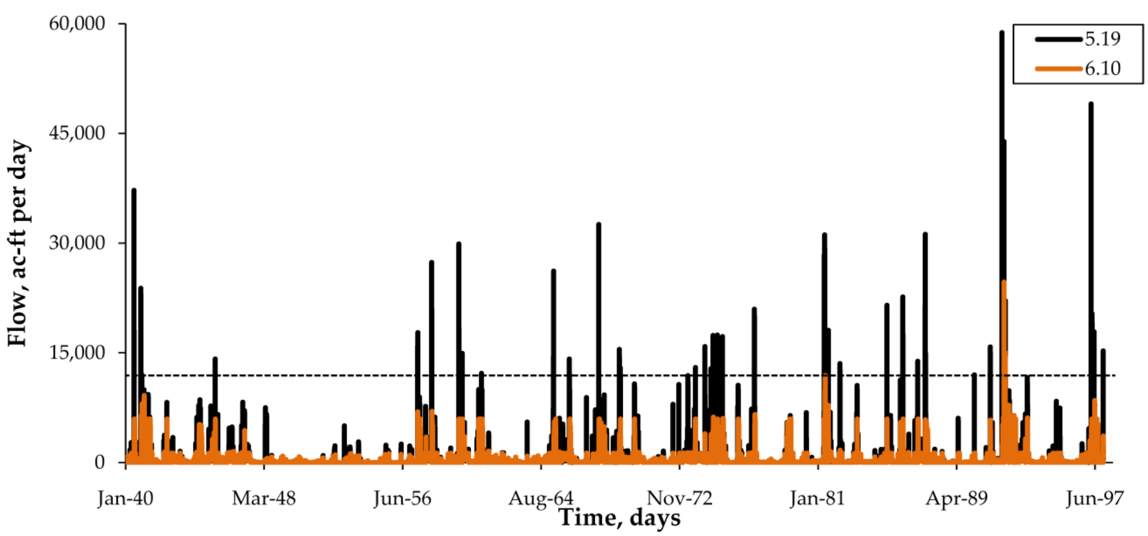

Figure 6.15 Regulated Flow at the Dam of Granger Lake, 516331

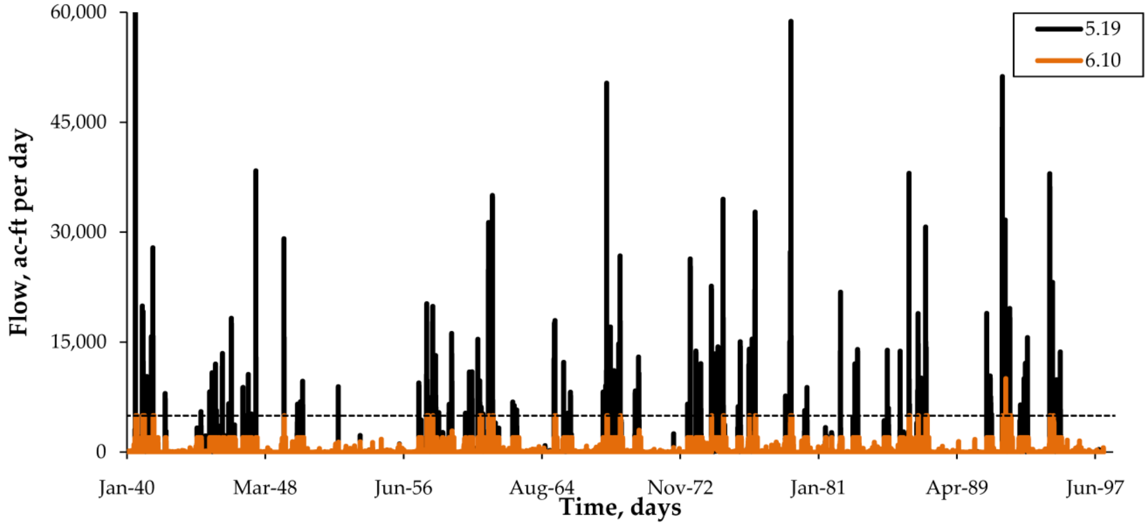

Figure 6.16 Regulated Flow at the Dam of Somerville Lake, 516431

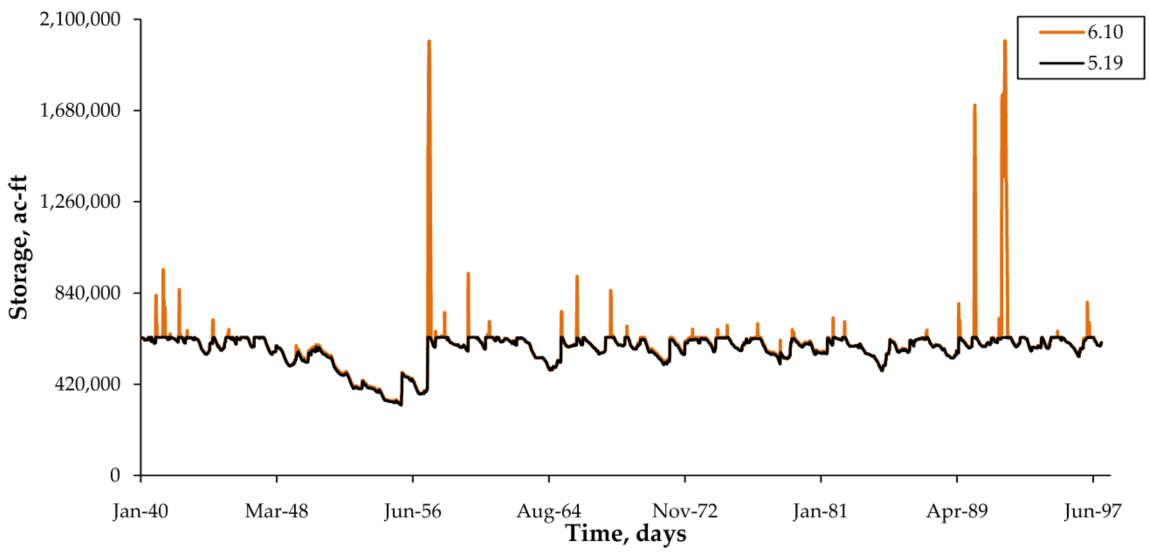

Figure 6.17 Storage in Whitney Lake, 515731

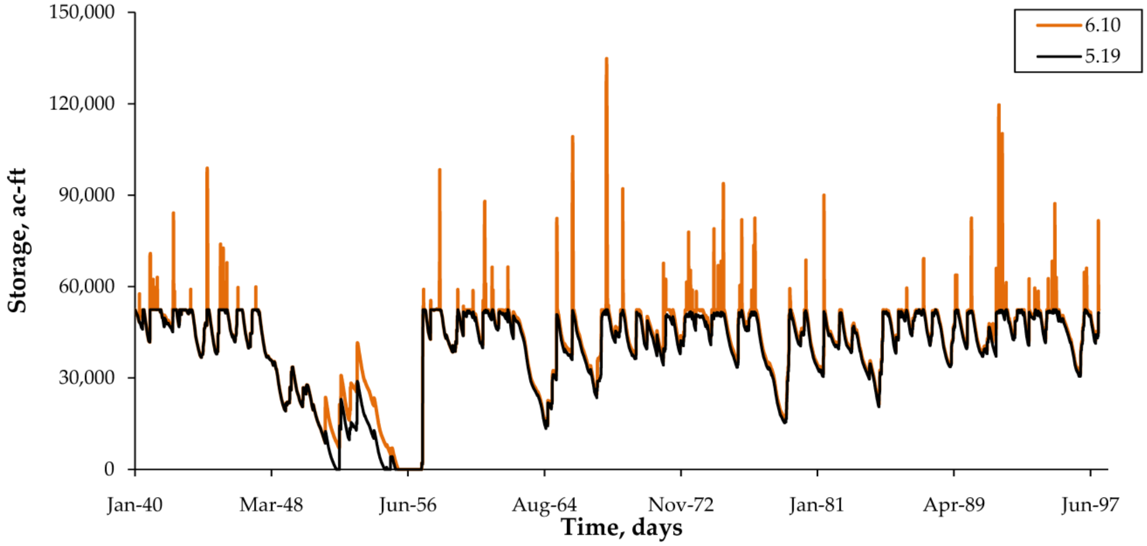

Figure 6.18 Storage in Aquilla Lake, 515831

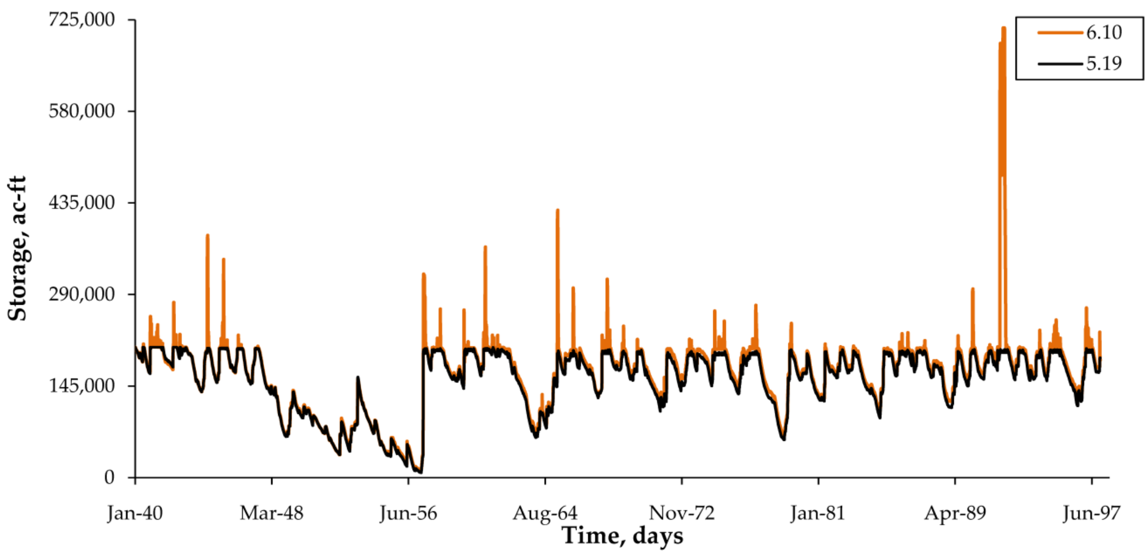

Figure 6.19 Storage in Waco Lake, 509431

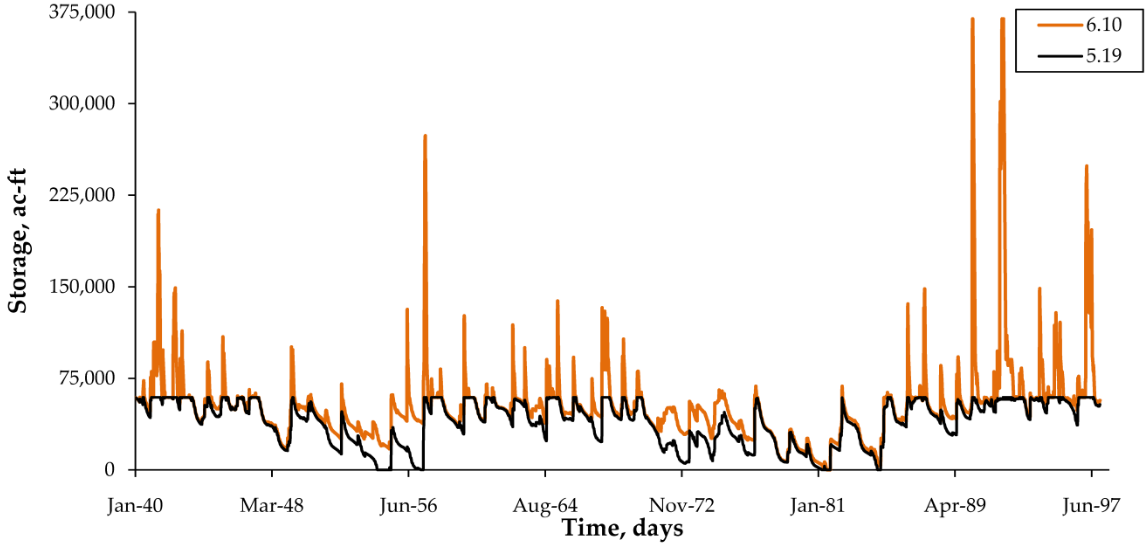

Figure 6.20 Storage in Proctor Lake, 509431

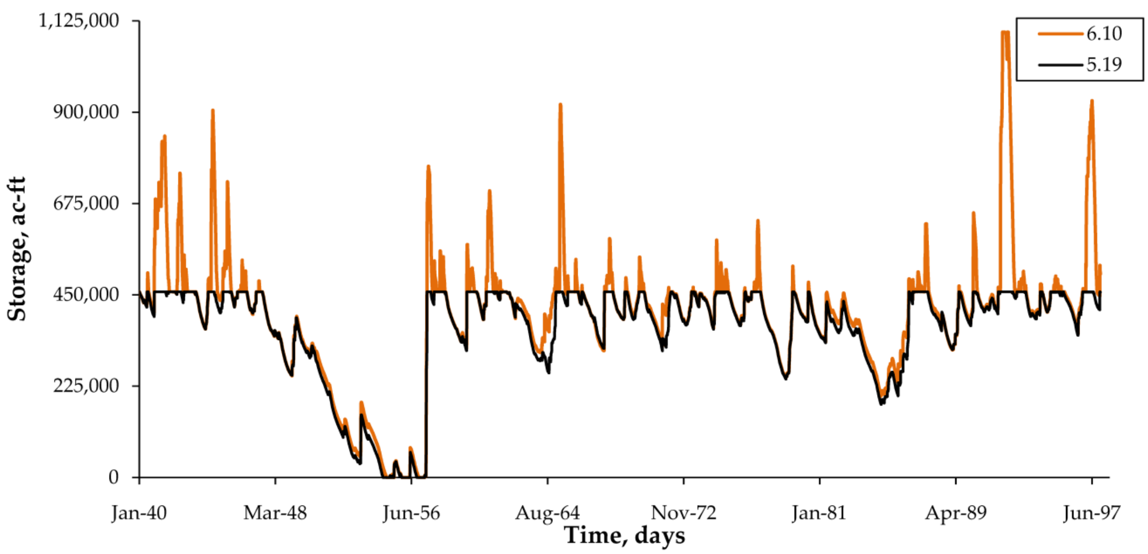

Figure 6.21 Storage in Belton Lake, 516031

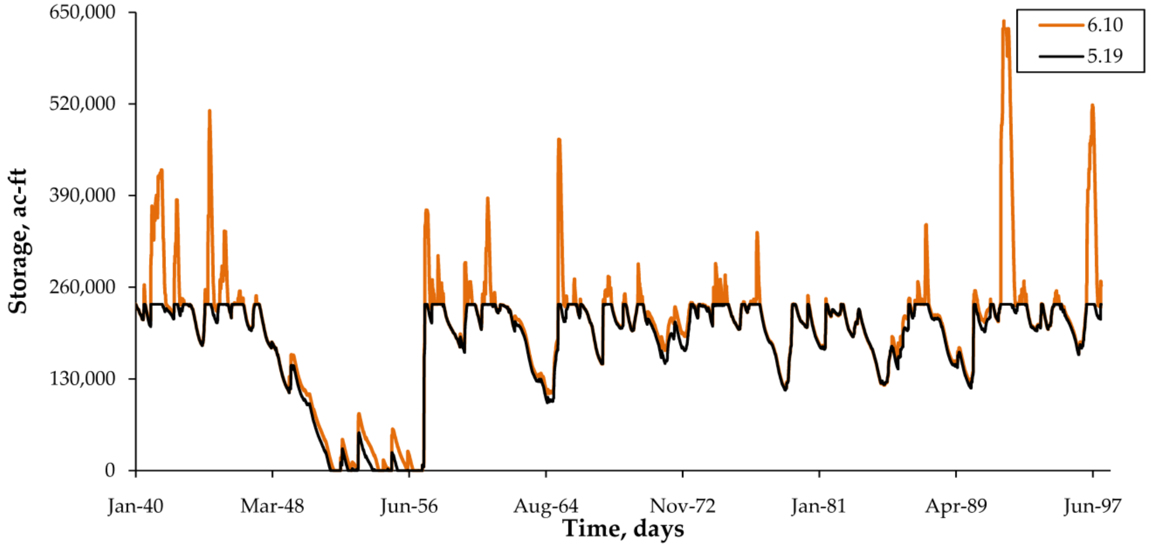

Figure 6.22 Storage in Stillhouse Hollow Lake, 516131

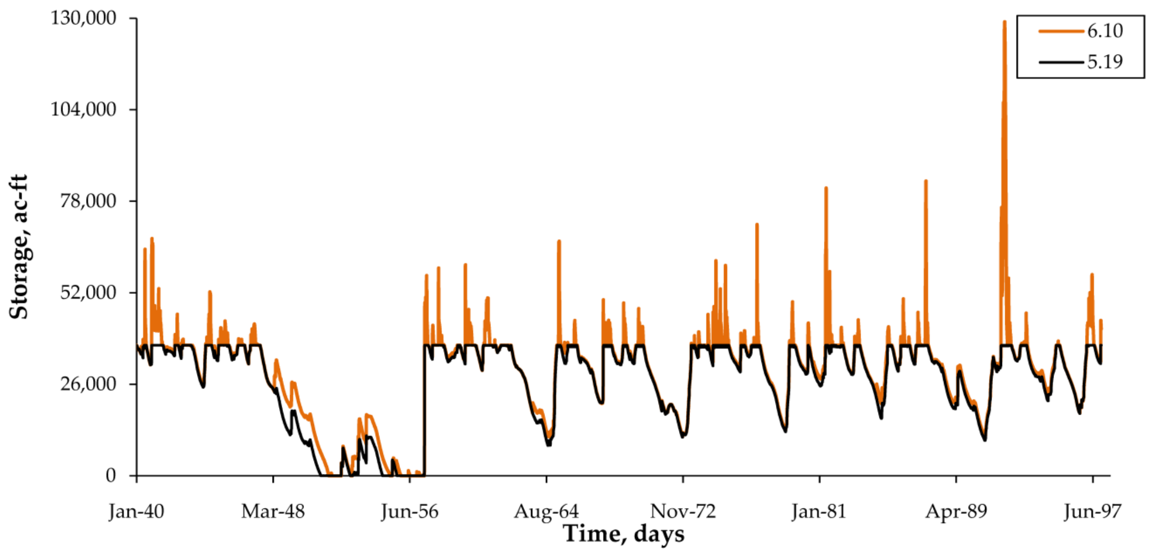

Figure 6.23 Storage in Georgetown Lake, 516231

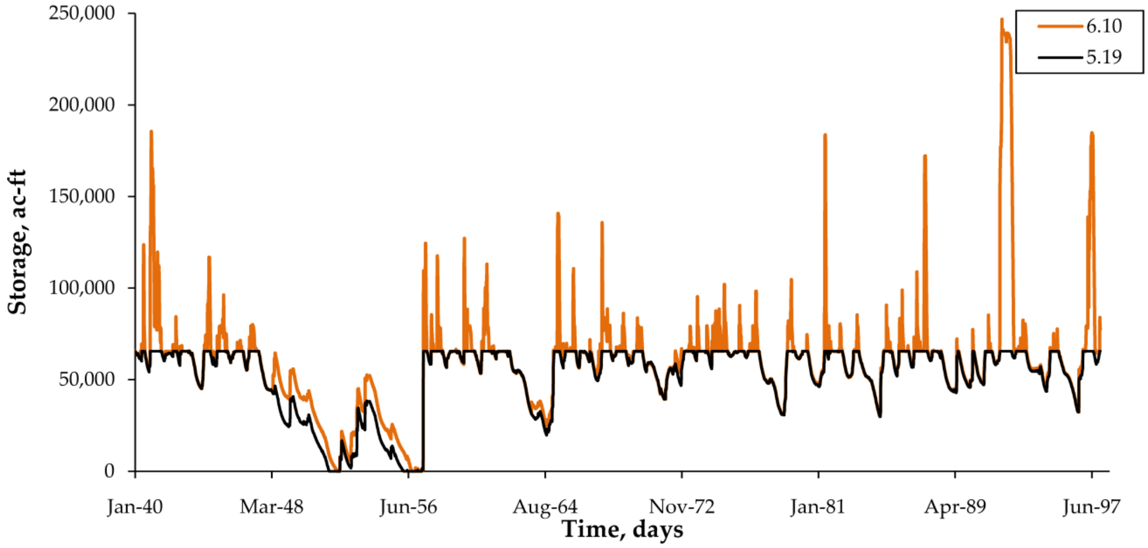

Figure 6.24 Storage in Granger Lake, 516331

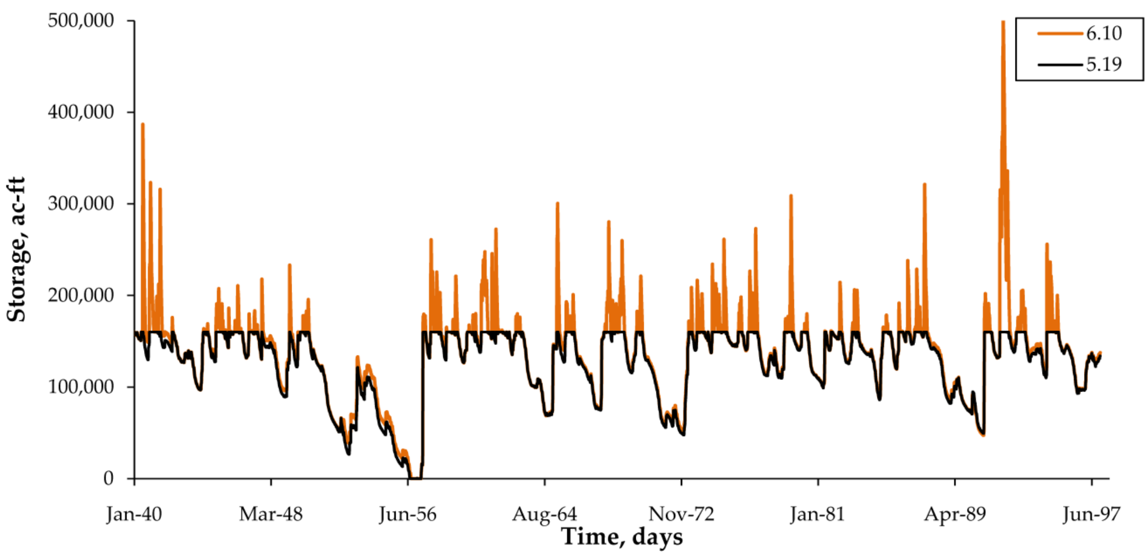

Figure 6.25 Storage in Somerville Lake, 516431

Daily regulated flow-frequencies are given in Table 6.10 for scenarios 5.19, 6.01, and 6.10. The inclusion of flood control reduces the maximum value of regulated flow during the simulation. The presence of flood control, however, increases the regulated flows at levels below the maximum value. The increase in regulated flow is most notable from the 10% to 50% exceedance levels in the table. An increase in regulated flow below the maximum level is due to flood control releases being made immediately after flood conditions have subsided. The release of flood storage can occur for many weeks or months following a major flood event. The release of flood storage can increase the duration of elevated downstream water availability instream flows. Whereas a major flood event may have moved through the system within a few days to a few weeks without flood control structures in the simulation, the hydrograph peaks are reduced but high flow duration is increased as result of including flood control in the simulation.

Regulated flow frequency is presented graphically in Figure 6.26 through Figure 6.31 for the six locations of the FF record flood flow gages. Only the top 50% of the flow exceedance range is presented in the figures to highlight the effect of flood control. The dashed lines accompanying the figures are set at the maximum allowable discharges at the downstream gages, with the exception of the Little River gage. The variable states of the Little River gage are plotted on Figure 6.30. The coding of the variable state FF record for the Little River gage is shown in Table 4.16 as a function of the total storage in Proctor, Belton, and Stillhouse Hollow.

Table 6.10 Flow Frequency of Daily Regulated Flow for Scenarios 5.19, 6.01, and 6.10, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.19, without Flood Control											
BRWA41	3401.02	11277.0	0.00	20.40	144.10	324.2	513.6	836.8	1920.2	7002.9	412903.0
BRBR59	8154.74	21316.0	0.00	287.59	676.97	1239.6	1750.2	2615.3	6008.7	19951.7	710389.6
BRRI70	12356.06	24898.2	0.00	730.17	1546.39	2265.5	3191.1	5165.0	11894.4	33020.8	635264.1
LEGT47	626.93	2323.4	0.00	0.20	15.95	47.2	89.5	152.1	373.8	1292.1	91829.5
LRLR53	1632.11	5599.1	0.00	16.66	72.93	151.4	235.9	376.0	936.9	3696.8	192764.5
LRCA58	2768.11	8545.6	0.00	39.67	142.15	298.6	482.1	783.5	1910.1	6358.0	287952.5
515731	2221.04	8100.4	0.00	0.00	65.79	169.5	280.4	464.3	1099.1	4083.8	187470.6
515831	148.51	1060.2	0.00	0.99	0.99	1.0	1.5	2.8	13.6	101.3	37727.5
509431	651.69	3455.8	0.00	0.00	0.00	0.0	1.0	8.5	192.7	1135.6	219359.5
515931	291.25	2119.3	0.00	0.00	0.00	3.9	10.0	23.1	74.4	433.2	195753.3
516031	939.88	3693.8	0.00	0.00	9.60	51.8	91.5	146.2	412.4	2070.8	164449.1
516131	417.92	2070.6	0.00	0.00	0.00	6.5	18.5	39.2	146.3	995.3	120467.3
516231	117.49	563.7	0.00	0.00	0.11	2.3	5.8	13.9	55.7	266.7	23854.6
516331	397.79	1526.0	0.00	0.00	3.40	19.5	46.0	88.0	264.1	886.2	58765.0
516431	439.45	2149.4	0.00	0.00	0.00	0.0	0.0	2.4	40.9	680.5	97763.8
Scenario 6.01, with Flood Control but without Regulated Flow Forecasting											
BRWA41	3387.97	9100.2	0.00	15.89	134.97	301.1	482.9	802.1	1904.8	7900.8	131024.4
BRBR59	8122.59	16391.5	0.00	285.79	689.47	1272.8	1862.9	3072.2	7827.9	22055.1	344247.2
BRRI70	12327.62	20624.7	0.00	738.31	1589.07	2346.8	3534.3	6258.3	13599.6	34715.0	282432.8
LEGT47	626.09	1800.6	0.00	0.01	15.64	46.8	90.5	160.7	476.8	1534.6	76783.6
LRLR53	1619.70	3008.4	0.00	16.68	74.14	158.1	253.5	440.2	1395.0	5372.9	80653.2
LRCA58	2759.01	5536.9	0.00	39.67	143.91	316.7	527.3	902.5	2866.8	8684.8	105684.0
515731	2217.32	7013.5	0.00	0.00	59.63	156.8	262.7	442.4	1045.6	4035.0	140841.1
515831	147.38	750.1	0.00	0.99	0.99	1.0	1.5	2.7	10.8	87.1	5950.0
509431	642.96	2425.7	0.00	0.00	0.00	0.0	0.6	6.7	157.2	1192.9	59505.0
515931	286.99	985.7	0.00	0.00	0.00	3.6	9.3	22.3	80.3	990.0	38207.4
516031	936.77	2115.5	0.00	0.00	7.34	47.0	86.5	143.6	472.0	3693.7	44175.6
516131	409.22	1202.1	0.00	0.00	0.00	4.2	16.6	35.6	135.2	1090.6	23134.1
516231	116.10	388.3	0.00	0.00	0.01	2.2	5.3	13.8	51.8	500.0	5950.0
516331	393.35	905.9	0.00	0.00	3.05	18.4	44.7	87.4	284.6	1290.0	18748.1
516431	437.73	953.8	0.00	0.00	0.00	0.0	0.0	4.4	94.3	1984.0	5083.1
Scenario 6.10, with Flood Control and with up to 3 Days Regulated Flow Forecasting											
BRWA41	3389.31	9036.8	0.00	15.09	133.56	298.7	478.3	791.0	1891.6	7979.2	130924.7
BRBR59	8123.59	16033.7	0.00	285.88	686.87	1277.2	1878.6	3137.0	7989.6	22180.7	336149.6
BRRI70	12332.92	20318.5	0.00	737.80	1591.09	2354.7	3579.6	6378.3	13684.3	34902.5	278198.8
LEGT47	625.98	1798.7	0.00	0.01	15.52	46.8	90.2	161.2	487.0	1544.0	76479.0
LRLR53	1620.89	3026.0	0.00	16.18	73.49	157.0	252.3	440.2	1415.4	5406.1	80038.8
LRCA58	2760.50	5471.8	0.00	39.67	143.33	316.7	529.6	916.5	3002.1	8895.0	104597.9
515731	2218.40	7033.4	0.00	0.00	58.12	154.4	258.6	436.6	1030.5	4009.8	140823.9
515831	147.37	748.3	0.00	0.99	0.99	1.0	1.5	2.7	10.6	86.8	5950.0
509431	642.91	2415.7	0.00	0.00	0.00	0.0	0.6	6.5	153.1	1185.8	44990.0
515931	286.81	996.9	0.00	0.00	0.00	3.3	8.9	21.0	78.5	990.0	39761.0
516031	936.39	2127.4	0.00	0.00	5.19	44.6	83.6	140.4	462.0	3678.5	45309.1
516131	408.72	1198.4	0.00	0.00	0.00	4.0	16.5	35.3	134.3	1102.9	23127.7
516231	116.05	408.0	0.00	0.00	0.00	1.9	5.2	12.2	47.3	500.0	5950.0
516331	393.09	927.6	0.00	0.00	2.32	17.0	41.9	83.6	272.8	1290.0	24687.5
516431	437.76	958.7	0.00	0.00	0.00	0.0	0.0	4.3	92.3	1984.0	10032.9

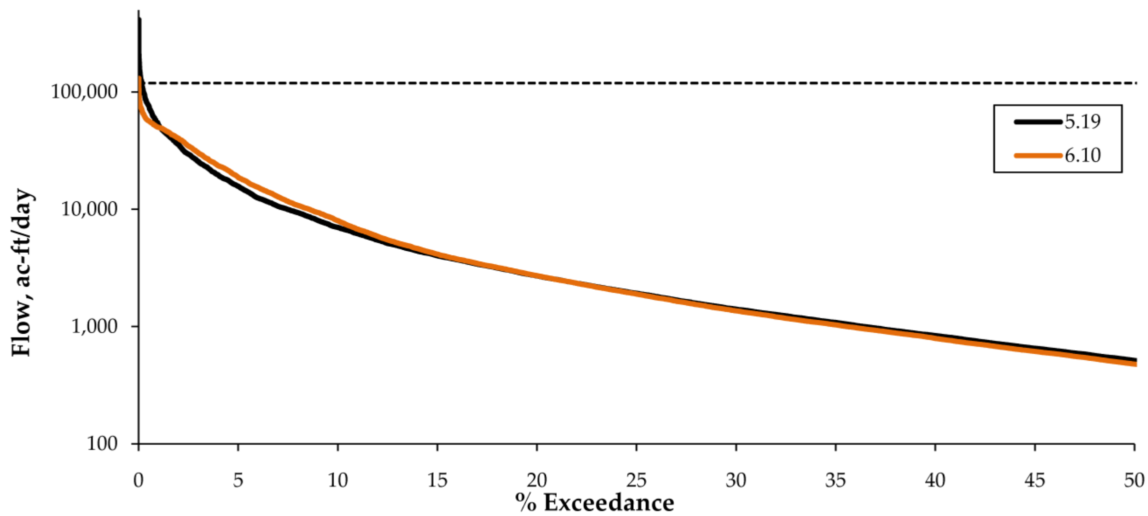

Figure 6.26 Flow Exceedance for the Waco Gage

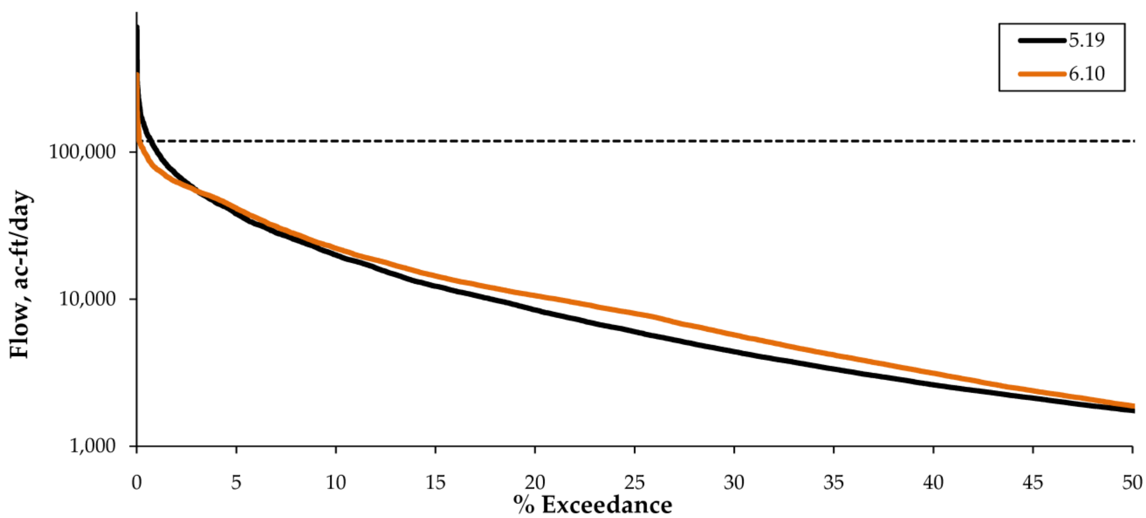

Figure 6.27 Flow Exceedance for the Bryan Gage

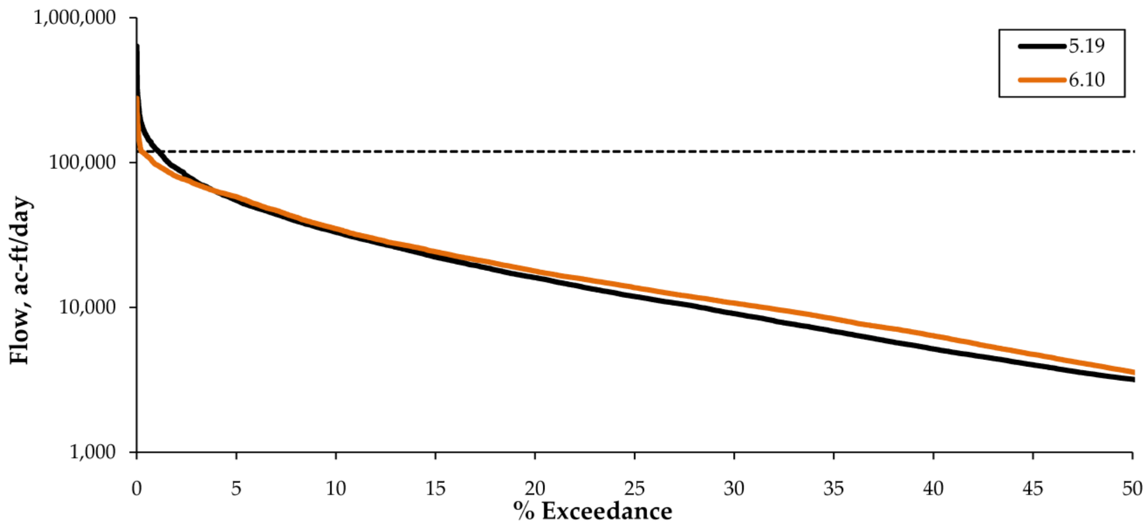

Figure 6.28 Flow Exceedance for the Richmond Gage

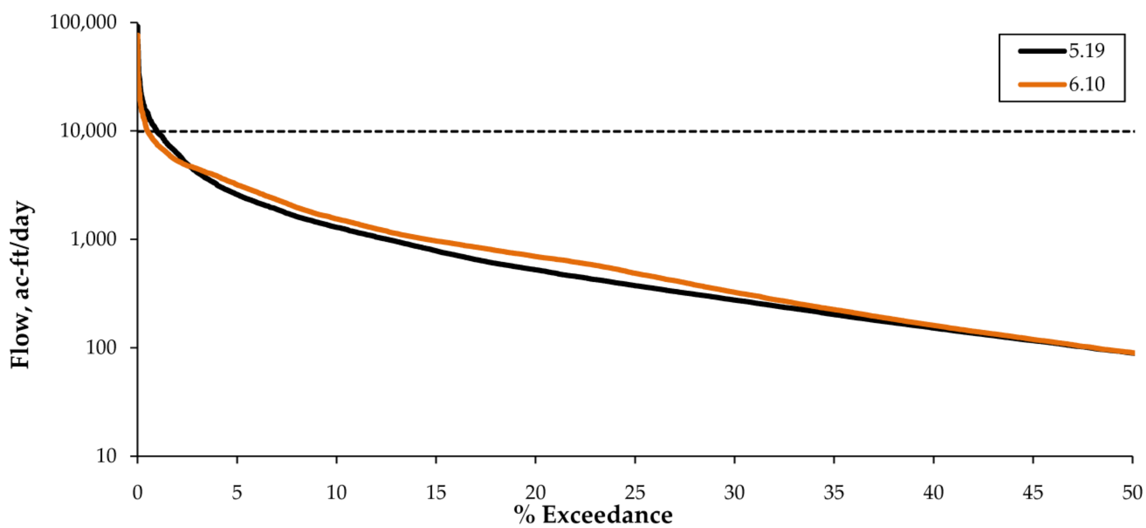

Figure 6.29 Flow Exceedance for the Gatesville Gage

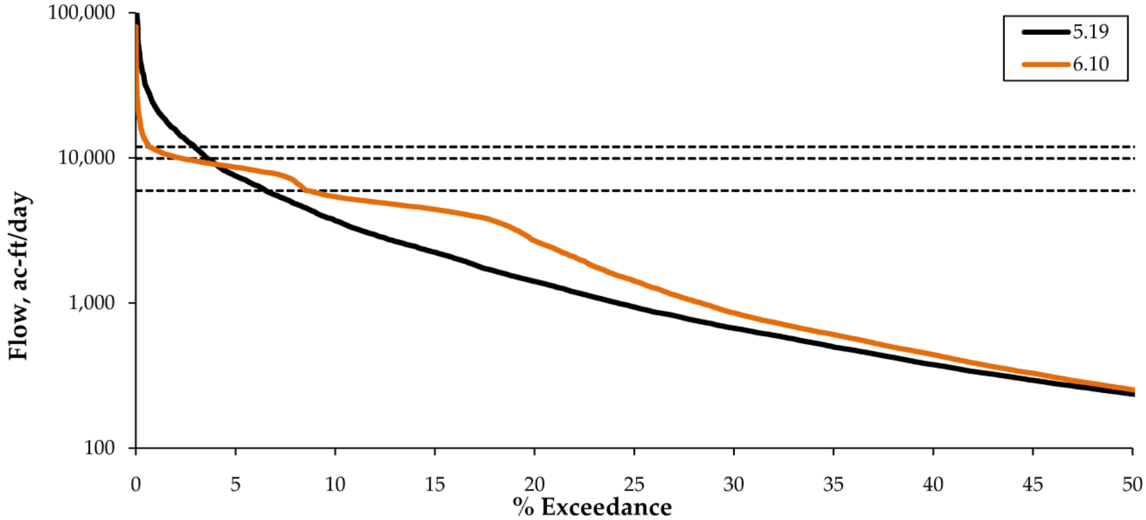

Figure 6.30 Flow Exceedance for the Little River Gage

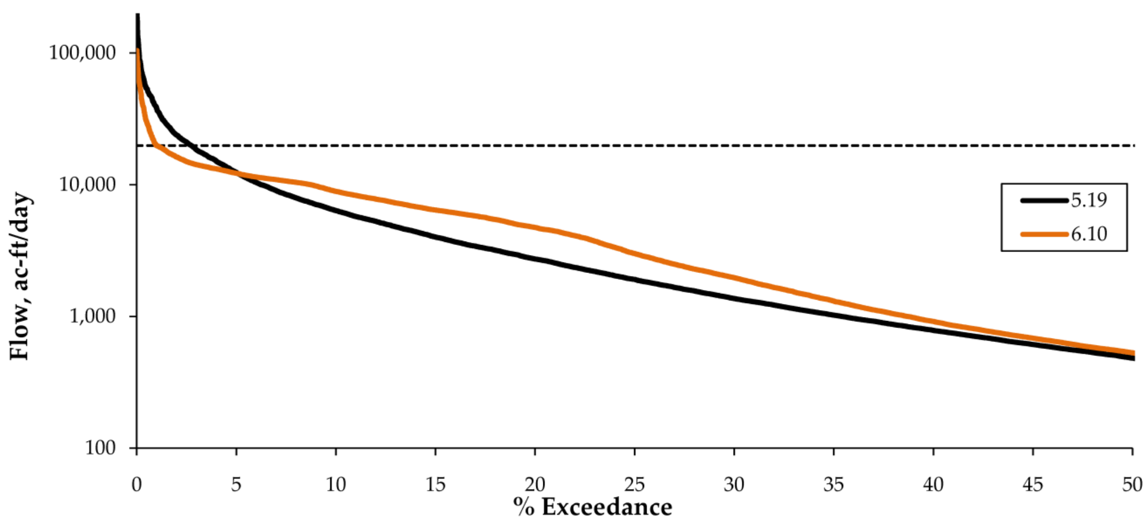

Figure 6.31 Flow Exceedance for the Cameron Gage

6.3.3 Effect of Flood Control on Simulated Water Availability

Flood control in SIMD can affect water availability for WR and IF record rights. Flood control pools, when added on top of an existing conservation pool, increase the storage capacity of the underlying reservoir. The type 1 WR record rights associated with the conservation pool cannot fill storage above the top of conservation. Flood control rights do not divert streamflow for storage except when regulated flows exceed the maximum allowable discharges at the downstream gages or the maximum allowable release rates at the dam. When flood control rights divert streamflow, conservation storage is filled before the flood control pool. The water right demands on conservation storage can potentially be met by stored water from flood control. Whitney and Waco are modeled as multiple separate conservation and flood control pools, which mitigates the connectivity described above between the conservation and flood control pools.

Flood control operations can also affect water availability in SIMD through flood control releases. The JU record parameter FRMETH is set to 1, causing flood control depletions and releases to be routed prior to the priority sequence. Flood control releases may occur for many weeks after a major flood event. These releases are placed into the stream and become part of the available water for any water right in the basin.

Daily unappropriated flow frequency is shown in Table 6.11 for scenarios 5.19, 6.01, and 6.10. Unappropriated flow is that portion of the regulated flow still available for appropriation after all water rights in the simulation have been considered. Similar to the increase in regulated flow observed for exceedances below the maximum value in Table 6.10, unappropriated flow tends to be greater at exceedances below the maximum value and suggests that flood control operations switch from storing to releasing between the 10% exceedance and the maximum value of unappropriated flow. For example, the 50% exceedance, or median, unappropriated flow at the Richmond gage increases from 342.5 in scenario 5.19 to 605.2 ac-ft per day in scenario 6.10 through the inclusion of flood control in the simulation.

Water right reliabilities at the control points of the nine flood control reservoirs are listed in Table 6.12. Water right mean annual shortages and volume reliabilities for the run-of-river rights are listed in Table 6.13 and Table 6.14, respectively. Water right reliabilities are listed for the scenario without flood control and the scenarios with flood control and with and without regulated flow forecasting. The inclusion of flood control in the simulation increases water right reliability, particularly for those reservoirs in which flood control reduces the number of days of zero conservation storage.

The time series of storage in Proctor Lake is shown in Figure 6.20. Zero storage capacity during the drought of record is eliminated during the 1950s' drought. Consequently, volume reliability in Table 6.12 for Proctor increases from 95.92% in scenario 5.19 to 99.11% in scenario 6.10. Alternative flood control pool operating schemes could result in different simulated sequences.

The run-of-river rights show a slight increase in volume reliability in all decades. However, these water rights have no access to storage. The flood control releases that occur during the wetter portions of the period of record generally do not coincide with the periods of streamflow shortage experienced by these water rights.

Table 6.11 Flow Frequency of Daily Unappropriated Flow for Scenarios 5.19, 6.01, and 6.10, ac-ft per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			% OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE								
Scenario 5.19, without Flood Control											
BRWA41	1897.46	7484.0	0.00	0.00	0.00	0.0	0.0	0.0	378.9	3802.7	165753.2
BRBR59	5036.41	15196.6	0.00	0.00	0.00	0.0	0.0	246.3	2948.0	13561.3	493747.9
BRRI70	9373.86	23307.6	0.00	0.00	0.00	0.0	342.5	1835.1	7649.7	27793.7	584669.1
LEGT47	355.13	1616.5	0.00	0.00	0.00	0.0	0.0	0.0	13.3	708.2	54619.7
LRLR53	1033.26	3821.2	0.00	0.00	0.00	0.0	0.0	0.0	152.8	2565.2	97425.1
LRCA58	1799.09	6166.5	0.00	0.00	0.00	0.0	0.0	0.0	708.8	4695.3	176801.5
515731	1295.94	5911.6	0.00	0.00	0.00	0.0	0.0	0.0	122.0	2335.1	137645.0
515831	92.21	705.3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	60.4	21064.7
509431	445.59	2129.7	0.00	0.00	0.00	0.0	0.0	0.0	0.0	838.1	60121.7
515931	108.24	711.2	0.00	0.00	0.00	0.0	0.0	0.0	0.0	60.0	27381.5
516031	641.72	2601.5	0.00	0.00	0.00	0.0	0.0	0.0	2.4	1473.2	72094.3
516131	280.27	1226.2	0.00	0.00	0.00	0.0	0.0	0.0	0.0	757.3	69358.4
516231	91.17	431.7	0.00	0.00	0.00	0.0	0.0	0.0	0.5	241.2	16249.0
516331	296.20	1202.1	0.00	0.00	0.00	0.0	0.0	0.0	71.6	782.9	43874.6
516431	397.77	1928.7	0.00	0.00	0.00	0.0	0.0	0.0	0.0	603.4	58769.0
Scenario 6.01, with Flood Control but without Regulated Flow Forecasting											
BRWA41	2015.14	6862.6	0.00	0.00	0.00	0.0	0.0	0.0	369.9	4144.7	79191.7
BRBR59	5265.19	12421.4	0.00	0.00	0.00	0.0	0.0	660.2	4387.6	15964.8	186537.2
BRRI70	9377.15	19286.7	0.00	0.00	0.00	0.0	596.5	2799.1	9471.7	29330.9	269607.6
LEGT47	307.91	925.8	0.00	0.00	0.00	0.0	0.0	0.0	44.0	914.1	16534.4
LRLR53	1129.09	2623.1	0.00	0.00	0.00	0.0	0.0	0.0	419.5	4625.9	66671.3
LRCA58	1882.01	4276.1	0.00	0.00	0.00	0.0	0.0	0.0	1525.1	6891.3	85301.3
515731	2217.32	7013.5	0.00	0.00	59.63	156.8	262.7	442.4	1045.6	4035.0	140841.1
515831	106.32	628.4	0.00	0.00	0.00	0.0	0.0	0.0	0.0	44.6	5949.0
509431	642.96	2425.7	0.00	0.00	0.00	0.0	0.6	6.7	157.2	1192.9	59505.0
515931	143.48	662.6	0.00	0.00	0.00	0.0	0.0	0.0	0.0	119.8	7767.5
516031	627.83	1694.0	0.00	0.00	0.00	0.0	0.0	0.0	33.2	2600.8	44175.6
516131	277.27	897.2	0.00	0.00	0.00	0.0	0.0	0.0	0.0	785.5	20271.3
516231	89.48	301.2	0.00	0.00	0.00	0.0	0.0	0.0	1.8	481.3	5944.9
516331	297.26	791.2	0.00	0.00	0.00	0.0	0.0	0.0	121.7	1279.1	18505.6
516431	401.00	931.7	0.00	0.00	0.00	0.0	0.0	0.0	0.2	1984.0	4960.0
Scenario 6.10, with Flood Control and with up to 3 Days Regulated Flow Forecasting											
BRWA41	2036.99	6930.0	0.00	0.00	0.00	0.0	0.0	0.0	368.4	4162.6	83966.5
BRBR59	5279.48	12241.7	0.00	0.00	0.00	0.0	0.0	699.2	4552.4	15972.6	186544.9
BRRI70	9382.61	18983.9	0.00	0.00	0.00	0.0	605.2	2872.2	9631.4	29456.2	259571.1
LEGT47	300.31	918.4	0.00	0.00	0.00	0.0	0.0	0.0	41.4	902.5	22590.4
LRLR53	1128.29	2631.9	0.00	0.00	0.00	0.0	0.0	0.0	410.3	4597.8	62054.2
LRCA58	1875.84	4156.6	0.00	0.00	0.00	0.0	0.0	0.0	1572.2	6993.0	79732.8
515731	2218.40	7033.4	0.00	0.00	58.12	154.4	258.6	436.6	1030.5	4009.8	140823.9
515831	105.89	625.9	0.00	0.00	0.00	0.0	0.0	0.0	0.0	44.4	5949.0
509431	642.91	2415.7	0.00	0.00	0.00	0.0	0.6	6.5	153.1	1185.8	44990.0
515931	148.20	690.6	0.00	0.00	0.00	0.0	0.0	0.0	0.0	125.3	14390.2
516031	634.91	1730.3	0.00	0.00	0.00	0.0	0.0	0.0	29.8	2662.4	45309.1
516131	279.36	907.5	0.00	0.00	0.00	0.0	0.0	0.0	0.0	795.0	20264.8
516231	89.30	319.4	0.00	0.00	0.00	0.0	0.0	0.0	1.0	440.8	5944.9
516331	298.20	810.6	0.00	0.00	0.00	0.0	0.0	0.0	110.5	1275.8	22949.4
516431	401.31	935.9	0.00	0.00	0.00	0.0	0.0	0.0	0.3	1984.0	8758.7

Table 6.12 Reliability Summaries of Water Rights at USACE Flood Control Reservoirs for Scenarios 5.19, 6.01, and 6.10

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
Scenario 5.19, without Flood Control											
515731	17973.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13938.4	482.69	96.12	96.54	96.1	96.1	96.1	96.1	96.4	97.0	97.4
509431	98033.9	4877.71	88.79	95.02	88.8	89.1	89.4	90.4	98.1	99.4	100.0
515931	20036.7	816.64	96.70	95.92	96.7	96.8	97.0	97.3	97.7	98.0	98.4
516031	112552.6	2628.22	96.84	97.66	96.8	96.8	97.0	97.0	97.4	97.8	98.4
516131	68142.1	4096.48	93.25	93.99	93.2	93.2	93.2	93.4	93.8	94.8	96.6
516231	13681.2	832.90	93.53	93.91	93.5	93.5	93.5	93.5	93.7	94.3	96.3
516331	19980.5	648.94	96.84	96.75	96.8	96.8	96.8	96.8	97.0	97.6	98.1
516431	48296.8	687.12	98.71	98.58	98.7	98.7	98.7	98.7	98.9	99.0	99.1
Total	412635.6	15070.71		96.35							
Scenario 6.01, with Flood Control but without Regulated Flow Forecasting											
515731	18058.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13924.2	343.54	97.56	97.53	97.6	97.6	97.6	97.6	97.6	97.6	97.8
509431	98087.3	4976.36	88.36	94.93	88.4	88.5	88.9	89.9	98.1	99.3	100.0
515931	19751.5	197.12	99.43	99.00	99.4	99.4	99.6	99.7	99.7	99.7	99.7
516031	112466.3	1853.59	97.41	98.35	97.4	97.6	97.7	97.7	98.0	98.4	98.9
516131	67966.7	1750.38	96.41	97.42	96.4	96.6	96.6	97.0	97.4	98.1	98.4
516231	13663.1	486.35	95.26	96.44	95.3	95.3	95.4	95.5	96.7	97.3	97.7
516331	19895.1	207.52	98.56	98.96	98.6	98.7	98.7	98.9	99.0	99.4	99.6
516431	48258.9	540.63	98.85	98.88	98.9	98.9	98.9	98.9	98.9	99.1	99.3
Total	412071.4	10355.49		97.49							
Scenario 6.10, with Flood Control and with up to 3 Days Regulated Flow Forecasting											
515731	18057.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13924.2	343.13	97.56	97.54	97.6	97.6	97.6	97.6	97.6	97.6	97.8
509431	98075.1	4962.86	88.51	94.94	88.5	88.6	88.9	89.9	98.1	99.3	100.0
515931	19749.8	176.25	99.57	99.11	99.6	99.6	99.6	99.7	99.7	99.7	99.9
516031	112466.6	1881.37	97.41	98.33	97.4	97.6	97.7	97.7	97.8	98.4	98.9
516131	67952.8	1658.08	96.55	97.56	96.6	96.7	96.7	97.1	97.4	98.1	98.6
516231	13662.0	480.08	95.26	96.49	95.3	95.4	95.5	95.7	96.7	97.3	97.7
516331	19895.1	210.23	98.56	98.94	98.6	98.7	98.7	98.9	99.0	99.4	99.6
516431	48258.9	539.66	98.85	98.88	98.9	98.9	98.9	98.9	98.9	99.1	99.3
Total	412041.9	10251.66		97.51							

Table 6.13 Mean Shortage for Selected Run-of-river Water Rights for Scenarios 5.19, 6.01, and 6.10

Selected Water Rights	Target Diversion ac-ft per year	Mean Annual Shortage, ac-ft per year		
		5.19	6.01	6.10
Dec. 31, 1929, and Senior, all uses	120,722	5,148	5,034	5,036
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	5,300	5,053	5,051
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	27,939	27,091	27,063
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	19,819	19,114	19,077
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	25,467	24,473	24,363
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,523	1,491	1,488
Jan. 1, 1980, and Junior, municipal use	75,000	17,575	17,035	16,965
Jan. 1, 1980, and Junior, non-municipal use	84,261	25,643	24,569	24,467
All Selected Water Rights	790,221	128,414	123,860	123,510

Table 6.14 Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.19, 6.01, and 6.10

Selected Water Rights	Volume Reliability, %		
	5.19	6.01	6.10
Dec. 31, 1929, and Senior, all uses	95.7	95.8	95.8
Jan. 1, 1930, to Dec. 31, 1939, all uses	93.0	93.3	93.3
Jan. 1, 1940, to Dec. 31, 1949, all uses	85.4	85.9	85.9
Jan. 1, 1950, to Dec. 31, 1959, all uses	82.3	83.0	83.0
Jan. 1, 1960, to Dec. 31, 1969, all uses	79.8	80.5	80.6
Jan. 1, 1970, to Dec. 31, 1979, all uses	67.5	68.2	68.3
Jan. 1, 1980, and Junior, municipal use	76.6	77.3	77.4
Jan. 1, 1980, and Junior, non-municipal use	69.6	70.8	71.0
All Selected Water Rights	83.7	84.3	84.4

CHAPTER VII
CASE STUDY SUMMARY AND GUIDANCE FOR APPLYING THE MODELING SYSTEM

Chapter VII summarizes the findings of each component of the case study as presented in Chapters III, IV, V, and VI. The process of assembling the data, creating SIMD input records, and analyzing simulation results for many alternative configurations and parameterizations for the case study simulation scenarios provides a basis for recommending ways to implement the results of this research in other basins. Adapting the Texas WAM System datasets is a particularly relevant application of the daily time step capabilities of SIMD that can further the status of water availability modeling throughout the state.

The focus of this research was the development of daily time step simulation capabilities for WRAP. The capabilities of the WRAP-SIMD sub-monthly simulation and WRAP-DAY pre-processor software were discussed and presented in the chapters of this dissertation through a case study. Additional details are available in the *Supplemental Manual* (Wurbs 2010c). The *Supplemental Manual* is updated regularly as new capabilities are added to the software. The case study of the TCEQ WAM dataset for the Brazos River Basin and San Jacinto Coastal Basin, Bwam, was organized in the following manner:

- Additional input data for adapting the monthly Bwam dataset into a realistic daily time step simulation, including flood control capabilities, were described in Chapter III.
- Input data were organized and synthesized into input records for SIMD in Chapter IV. DF, RT, FR, and FF records were constructed,

and alternative parameterizations for disaggregation, routing placement, forecasting, and target distribution were discussed.

- Simulation results for 19 different daily Bwam scenarios were presented in Chapter V. The goal of differential simulation comparison was to gain insight into the relative effects of the various options and parameter settings available in the SIMD software. Emphasis was given to the effect on water availability. Results were presented for regulated and unappropriated flow frequency, water right reliability, and water balance makeup.
- Simulation results for 12 different daily Bwam flood control scenarios were presented in Chapter VI. The base flood control operating configuration was derived from the U.S. Army Corps of Engineers nine major flood control reservoirs in the Brazos River Basin. Downstream regulated flow forecasting periods were the only parameters adjusted between the simulation scenarios. Comparison was made to a daily simulation without flood control. Reduction of peak annual regulated flow, alteration of regulated and unappropriated flow frequency, and the effect on water right reliability were considered for a daily simulation scenario without flood control and between scenarios with and without flood control regulated flow forecasting.

7.1 Daily Data and Parameter Selection

Existing SIM datasets can be converted for use at sub-monthly time steps with SIMD by the addition of a single JT record in the DAT file. However, simulation realism may be lacking for sub-monthly times step simulation if additional data is not provided to capture the presence of flow variability and flow routing at the sub-monthly level. Alternatively, the DAT and hydrology files may be developed for SIMD without an existing monthly dataset. Daily flows can be read as direct input for representing the flows at each control point.

The following features of SIMD are used exclusively for daily simulation:

- routines for setting the number of daily computational time steps contained in each month and subdividing monthly naturalized flow volumes into daily time steps;
- options for setting and varying diversion, hydropower, and instream flow targets over the daily time steps within each month;
- options for reading daily naturalized flows from an input file;
- alternative options for disaggregating naturalized monthly flows to daily time intervals;
- options for determining current-day available streamflow for WR record water rights based on a forecast simulation over a future forecast period specified for individual water rights;
- forecasting of remaining channel capacity for FF/FR record flood control operations;
- alternative methods for routing of streamflow adjustments; and
- aggregation of daily simulation results to monthly values and recording of simulation results at daily and/or monthly time steps.

Constructing daily simulation datasets, assuming the conventional monthly DAT and hydrology files are available, primarily involves selecting a method of disaggregating the monthly flows to daily flows and calibrating routing parameters that can be paired with the disaggregated daily flows. Other features of SIMD, such as target building and forecasting, can greatly affect the simulation output and should be tested as part of a simulation sensitivity analysis. Chapter V examined the effect on simulation output for the choice of the various parameters available in SIMD.

7.1.1 Disaggregation of Monthly Naturalized Flow

The selection of the disaggregation method when building a SIMD dataset will affect water availability and regulated flow variability in the simulation output. Daily naturalized flows may be provided directly in a SIMD input DCF without monthly flows. Alternatively, daily flows may be developed by disaggregation of monthly naturalized flows using optional methods incorporated within SIMD and DAY. The choice of disaggregation method depends largely on the availability of daily flow data representative of natural conditions. WRAP provides flexible options to design flow disaggregation strategies for a broad range of situations ranging from having extensive daily flow data available to having no daily flow data.

If daily naturalized or unregulated flows are available, those data should be used as input to SIMD for the disaggregation of monthly naturalized flow volumes. Ideally, the daily naturalized flows should cover the monthly naturalized flow period of record. Repetition of daily flow patterns that are shorter than the monthly naturalized flow period of record will be done automatically by SIMD. However, repeating a daily pattern over the monthly period of record can result in mismatches of high and low flow conditions between the daily pattern and the monthly volumes. Mismatched flow conditions will have implications for water availability, regulated flow pattern and possibly flood control. The locations of daily naturalized flows ideally should have a broad spatial spread over the basin and cover the main stem of the river as well as the major tributaries. Spatial distribution of the daily flow patterns should cover the diverse flow characteristics throughout the basin without leaving large distances between pattern locations. Large distances between pattern locations can reduce the calibration quality of routing parameters that are based on the daily naturalized flows.

The approach taken in Chapters IV, V, and VI was to utilize the monthly naturalized hydrology of the existing TCEQ Bwam dataset. Disaggregation of the monthly flow volume was conducted with the flow pattern option. Daily unregulated flows at 34 locations in the Brazos River Basin from the USACE SUPER model were used to disaggregate the Bwam monthly naturalized flows. The monthly total naturalized flows in the WAM served as a consistent total water volume between simulations conducted with SIM and daily simulations conducted with SIMD and allowed comparisons between monthly and sub-monthly simulations to be made for the effects of time step.

7.1.2 Routing Parameters

The lag and attenuation routing method was developed specifically for routing flow changes in SIMD and is the recommended option for most WRAP applications. The lag and attenuation parameters can be calibrated for a reach of any length and with any average travel time. An adaptation of the Muskingum method is also included in the modeling system. However, Muskingum may not be appropriate for reaches of short length and travel time. The program DAY provides a set of options for calibration of parameters for either routing method, both of which are covered in the *Supplemental Manual*. Calibrated routing parameters will be reflective of all time steps selected for inclusion in the calculation of the objective function. Therefore, selection of the objective function in DAY and selection of valid time steps for the calibration will influence the value of the calibrated parameters.

7.1.3 Forecasting Periods

Streamflow forecasting can be applied to protect water availability for senior rights from past upstream junior water right actions and to reduce the incidence of over-appropriation when the routing option WRMETH 1 is used. If WRMETH 2 is used, forecasting is used to protect the water balance from over-appropriation. All water rights can be assigned the same forecasting period, or the forecasting period can be customized for each water right or groups of water rights. Selecting forecasting periods based on priority number will ensure the most junior water rights in the basin are simulated as curtailing their streamflow depletions first to meet downstream senior needs regardless of location or particular flow events.

7.1.4 Water Right Target Building

The 18 steps in the target-setting process in SIMD are described in the *Supplemental Manual*. Converting a monthly simulation into a daily simulation requires review of the intended water right target-setting options. For example, backup water rights can be simulated as attempting to recover the shortage of the primary water right on a day-to-day shortage basis or can be simulated as attempting to recover the total monthly shortage from the previous month. If the primary water right is utilizing a positive value of ND and SHORT, the day-to-day shortages may not be actual shortages prior to the end of the month. In such cases, the backup water right should use the option to recover the total monthly shortage for the previous month. The target-setting options on the TO record also require examination. For example, TO records in the monthly model that build a target based on the reservoir drawn down in the previous month, TOTARGET option -3, could be set to build targets in SIMD according to the previous day's reservoir drawdown or the end-of-month reservoir drawdown in the previous month. Choice of the previous day's reservoir drawdown can result in very large total monthly targets being set.

In the Bwam dataset, all backup water rights are assigned to recover the primary water right's total monthly shortage in the previous month. All TO record options are set to operate on a total prior monthly basis unless otherwise required by the water right.

7.1.5 Water Right Target Distribution

The number of days per month for meeting a monthly water demand target can be set with parameter ND. If ND is greater than zero, the monthly target demand will be distributed in the first ND days of the month. After the first ND days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target-building process if the SHORT parameter option is activated. Use of ND and SHORT enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

The use of ND and SHORT can increase water right reliability. However, judgment must be applied in selecting appropriate values of ND. Simulating water rights with a small value of ND could unrealistically represent their real-world pumping rates or could violate daily pump rate limitations in their water right permits.

7.2 Water Availability Simulations

A large number of optional input data and parameters may be used in a daily simulation. The optional information can be categorized as either hydrologic or water management input. Daily hydrologic inputs include routing parameters, disaggregation methods, and daily flow pattern data. Water management inputs are more numerous but include forecasting methods, forecasting periods, and water right target building and monthly distributions. A complete listing and description of SIMD inputs can be found in the *Supplemental Manual*.

The objective of Chapter V was to provide simulation results and to make comparisons for various SIMD parameterizations. Water right reliability, reservoir storage, regulated and unappropriated flow at the major reservoirs, and selected stream gages were provided as a basis for comparison. The focus of the simulation and result reporting in Chapter V was the full authorization dataset, Bwam3.

Simulation results in Chapter V were organized according to the examination of the following aspects of a daily simulation:

- monthly versus daily simulation time step size,

- methods for disaggregating naturalized flow from monthly to daily values,
- placement of routed changes to flow,
- methods for forecasting water availability,
- forecasting periods, and
- daily water right target distribution.

The daily simulations in Chapter V did not consider flood control operations. Flood control was addressed in Chapter VI. Nine major reservoirs in the Brazos River Basin with flood control capability were examined for the ability to reduce regulated flow below flood flow limits at downstream gages and at the dam sites. Adding flood control to the simulation dataset can also affect water availability and regulated flow frequency.

7.2.1 Monthly versus Daily Simulation Time Step Size

The conventional monthly SIM simulation was compared with a daily time step simulation in SIMD without routing, with uniformly disaggregated monthly to daily naturalized flows, uniformly distributed monthly targets, and no forecasting. Time step size was the only difference between the two simulations. The monthly Bwam simulation covered 696 monthly time steps for the period of record. The daily simulation covered 21,185 time steps for the same period of record.

Nearly identical results were obtained for the monthly and daily simulations with respect to reservoir storage, water right reliability, and regulated and unappropriated flows. Slight differences in Bwam3 results between SIM and SIMD are attributable to the computation of reservoir surface area with a single monthly time step or between 28 and 31 daily time steps. Total monthly net evaporation-precipitation in SIMD is dependent on daily computations of reservoir surface area based on daily average storage volume. Because reservoir surface area has a non-linear relationship with storage volume, a single monthly time step value of monthly average surface area will differ from the monthly average surface area computed from the daily time steps in the month. Differences in net evaporation-precipitation result in different reservoir drawdowns and streamflow depletions for refilling. Additional differences in the current conditions dataset, Bwam8, are attributable to return flow discharge timing. Return flows in SIM were placed in the stream before the priority sequence in the next month. Return flows in SIMD were placed in the stream before the next day.

7.2.2 Disaggregation of Monthly Naturalized Flow

Three methods of disaggregating the Bwam monthly naturalized flows to daily naturalized flows were examined. The uniform method of disaggregation divides the total monthly naturalized flow by the number of days in the month. The linear interpolation method uses the variation in month-to-month total naturalized flow to develop an interpolation spline. Monthly flows are divided into daily flows based on the area occupied under the spline. Daily unregulated flow time series at 34 locations at and below the dam site of Possum Kingdom Lake were used as patterns to distribute monthly Bwam naturalized flow. The unregulated flow time series are inputs to the SUPER flood control model of the U.S. Army Corps of Engineers Fort Worth District. The SUPER unregulated flow data are considered to be good approximations of daily naturalized flows.

The greatest difference in SIMD simulation output for the various parameterizations examined in this chapter occurs when the daily SUPER flow patterns are used to disaggregate the Bwam monthly naturalized flow. As compared to the uniform or linear interpolation methods of disaggregation, the daily flow pattern method contains significant intra-month streamflow variability. The high degree of intra-month variability reduces the ability of water rights to meet their entire monthly target demands. Increased water right shortages place a greater demand on stored water backup.

Figure 7.1 shows a hypothetical streamflow time series and water right target demand. Streamflows are shown for uniformly disaggregated monthly flow volumes and for daily flow pattern disaggregation. Both streamflow time series have equal monthly total volumes. The water right target is met in all days shown with the uniformly disaggregated flows except in March when streamflow availability is nearly zero. Conversely, the streamflow variability created by the daily flow pattern disaggregation results in frequent shortages in meeting the water right target. If the water right cannot forgo constant daily diversions and recover shortages during periods of greater streamflow, the water right will experience greater shortages with the daily flow pattern method of disaggregation.

Hydrology in the monthly SIM model is equivalent to the uniform method of disaggregation in SIMD. Monthly aggregated naturalized hydrology versus a daily naturalized flow pattern creates the greatest difference between simulating water availability with a monthly versus daily time step.

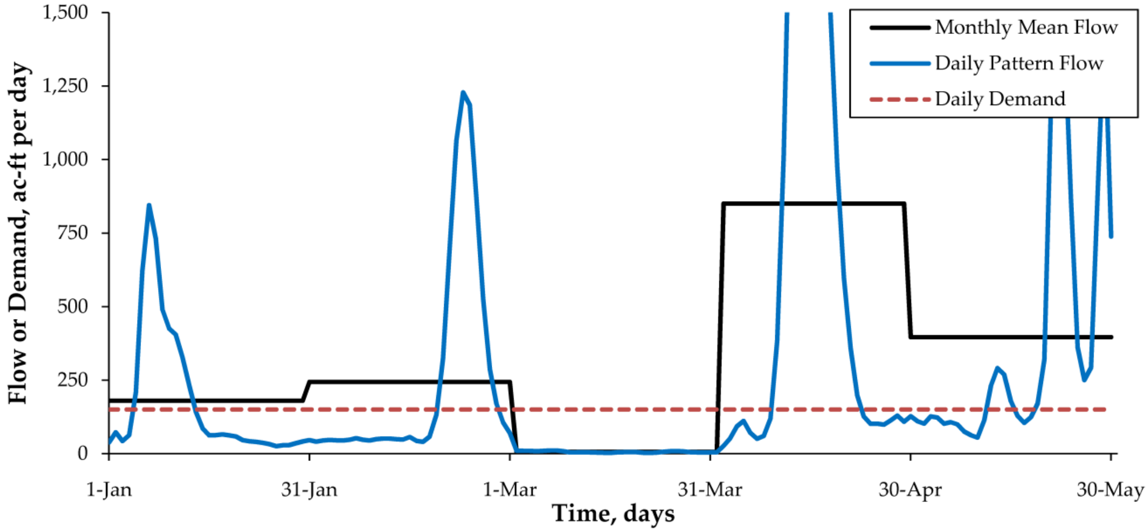

Figure 7.1 Hydrologic Distribution versus Water Right Demand

7.2.3 Placement of Routed Changes to Flow

If routing is used in SIMD, streamflow depletions and return flows from previous days can be routed downstream each day until they reach the outlet using two alternative methods. Past changes to flow can be routed before the priority sequence. This method allows past junior depletions or returns to directly affect the water availability of all water rights. This method is the more realistic of the two routing methods. Forecasting for future downstream senior shortages can reduce the impact on water availability from depletions made by upstream juniors. Alternatively, the changes to flow can be routed within the priority sequence at the priority of the water right that made the depletion or return. This method protects senior water rights from being directly impacted by the changes to flow of junior rights. However, because water availability to senior rights is not reflective of previous junior changes to flow, senior rights may deplete flows that were appropriated by juniors in previous days. The application of water availability forecasting with forecasting methods 6 or 7 is essential if this method of routing is chosen to protect the water balance due to over-appropriation. Over-appropriation can lead to artificially elevated water right reliability.

7.2.4 Methods of Forecasting Water Availability

Forecasting methods 1, 3, and 5 were applied to all water rights in the Bwam DAT file. Optionally, any forecasting method can be selected for an individual water right with the DW record in the DAT file, or for individual or groups of water rights with the DW/SC records in the DCF file. Forecasting methods 1 through 5 utilize measurements of future downstream senior shortages as a quantity to reduce present-day water availability. Forecasting method 1 records the maximum of the daily totals of downstream senior shortages over the forecast period. Forecasting method 3 records the maximum shortage of any single downstream senior water right during any day of the forecasting period. Forecasting method 5 cancels water availability to the water right applying forecasting if any downstream senior water right experiences a shortage of any size during any day of the forecast period. Forecasting methods 2 and 4 are analogous to methods 1 and 3, respectively, except that methods 2 and 4 do not increase the measured downstream senior shortage by the amount of channel loss between the upstream right and the downstream senior rights.

Forecasting methods 1 and 3 produced similar overall water availability as compared to the simulation without forecasting. Senior water rights experienced a slight increase in water availability, and there was a decrease in the incidence of water balance makeup with the application of forecasting.

Forecasting method 5 caused a significant impairment of water availability and should be used with caution.

Forecasting methods 1 or 2 may be more applicable in instances when junior rights lie on the same tributary as their common downstream senior rights. Junior rights in a series configuration with the downstream seniors should pass the total downstream senior shortage to protect senior water availability. Forecasting methods 3 or 4 may be more applicable in instances when junior rights lie on different tributaries from each other. Junior rights distributed on multiple upstream tributaries affect different sources of inflow for their common downstream senior rights. Passing inflow equal only to the largest single downstream senior shortage may allow juniors to meet their demands while seniors receive adequate cumulative protection of inflows on multiple tributaries.

7.2.5 Forecasting Periods

Forecast periods of 1, 3, 5, and 7 days were applied to all water rights in the dataset. Additionally, forecast periods were incremented from 0 to 5 days based on the criteria in Table 4.11. Water rights with the most senior priority dates were assigned 0 or no forecasting, whereas water rights with the most junior priorities were assigned either 4 or 5 days of forecasting based on their type of use. Reliability increased up to a global 5-day forecast period. A global forecast period of 7 days began to impair overall water availability. All forecast periods reduced the occurrence of water balance makeup over the scenario without forecasting.

There may be an advantage to assigning forecast periods according to priority date and use. Forecast period assignment can be approached from the perspective of addressing the multi-objective optimization of:

- minimizing impacts to senior rights' water availability caused by junior right streamflow depletions in previous days,
- minimizing over-constraining water availability with excessive forecast periods,
- allowing adequate reservoir refilling, and
- minimizing over-appropriation that triggers instances of water balance makeup.

By assigning an ascending forecast period based on ascending priority number, the most junior rights in the basin are always curtailed first. Curtailment of the most junior rights reduces the likelihood of more senior rights being curtailed to meet the needs of the most senior rights.

7.2.6 Daily Water Right Target Distribution

SIMD offers the option to set the number of days, ND, in which the target demand can be met. If ND is greater than zero, the monthly target demand will be distributed in the first ND days of the month. After the first ND days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target-building process if the SHORT parameter option is activated. Use of ND and SHORT enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

The ND parameter was set for water rights according to their use type as listed in Table 4.12. Fewer days for recovering shortages occur the closer the value of ND is to the actual number of days in the month. Municipal use rights have a near-constant monthly demand and, accordingly, were assigned an ND value of 28 days. Industrial, mining, and hydropower rights were assigned an ND value of 20 days. Agricultural rights were assigned an ND value of 14 days to reflect possible on-farm storage capacity or flexibility in diverting water whenever it becomes available during the month.

Mean shortages were decreased with the utilization of the ND and SHORT parameters relative to the simulation scenario with uniform monthly target distribution and no shortage recovery. Shortages were decreased further for senior rights with a priority date senior to 1970 with the utilization of forecasting.

The use of ND and SHORT can increase water right reliability. However, judgment must be applied in selecting appropriate values of ND. Simulating water rights with a small value of ND could unrealistically represent their real-world pumping rates or could violate daily pump rate limitations in their water right permits.

7.2.7 Comparison of Monthly and Daily Simulation Results

The monthly SIM simulation and a daily SIMD simulation of the Bwam3 dataset are presented below. The parameter settings of the two simulation scenarios are listed in Table 7.1. The SIMD simulation compared against the SIM simulation does not necessarily represent an optimal or recommended set of parameterizations for daily simulation. Rather, scenario 5.19 represents an application of generalized parameter settings on a large number of water rights in the Bwam dataset to protect senior water rights, to reduce occurrences of over-appropriation, and to represent realistic water uses and interactions of water rights at a daily time step. Alternative parameterizations for individual water rights may be appropriate.

Tables and figures of the SIM and SIMD simulation results are presented. Table 7.2 lists end-of-month storage frequency, Table 7.3 lists monthly regulated flow frequency, Table 7.4 lists unappropriated flow frequency, Table 7.5 lists the water right reliability summary at the locations of the BRA reservoirs, and Table 7.6 lists run-of-river water right reliability. Figure 7.2 through Figure 7.13 show time series of reservoir storage contents for each of the BRA water supply reservoirs in the Brazos River Basin.

Table 7.1 Parameters per Simulation Scenario in Section 7.2.7

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, WRMETH	Disaggregation Option, DFMETHOD	Target Distribution Option, ND	Forecast Period, FPERIOD	Forecast Option, FCMETH
5.01	month	Bwam3	na	na	na	na	na	na
5.19	day	Bwam3	lag-att	1	daily pattern	Table 4.12	Table 4.11	1

Table 7.2 End-of-month Storage Frequency for Scenarios 5.01 and 5.19, ac-ft

CONTROL		STANDARD	% OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES IN THE TABLE								
POINT	MEAN	DEVIATION	100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
					Scenario 5.01, Monthly Time Step						
515531	668900.	74978.	271009	472525.	530473.	571645.	637247.	697424.	724739.	724739.	724739.
515631	136235.	25563.	30631	59945.	79936.	102904.	126190.	147316.	155000.	155000.	155000.
515731	591543.	54633.	366459	410314.	472895.	516386.	574677.	608762.	631209.	636100.	636100.
515831	44579.	9682.	2011	14788.	22103.	33203.	40452.	47339.	52400.	52400.	52400.
509431	165550.	40175.	53095	64450.	79338.	96251.	144600.	179096.	199119.	201854.	206555.
516531	186786.	46721.	19773	43996.	78038.	121425.	171559.	201445.	225400.	225400.	225400.
515931	47931.	13163.	2993	11370.	18961.	28032.	41725.	52109.	59400.	59400.	59400.
516031	397450.	84760.	91488	125201.	183613.	263842.	380235.	430234.	457600.	457600.	457600.
516131	191992.	63789.	0	4329.	22162.	74014.	181269.	219386.	235700.	235700.	235700.
516231	29736.	9550.	0	114.	7351.	16070.	25232.	33653.	37100.	37100.	37100.
516331	55843.	14300.	0	10558.	23372.	35121.	51387.	62444.	65500.	65500.	65500.
516431	131827.	35010.	0	35492.	59650.	76495.	116463.	145590.	160110.	160110.	160110.
Total	2648372.	390803.	1271876	1494576.	1778397.	2105681.	2518298.	2779618.	2947680.	3001883.	3015578.
					Scenario 5.19, Daily Time Step						
515531	635992.	98813.	227291	380914.	445258.	492423.	584924.	671388.	718963.	724292.	724739.
515631	130500.	31599.	0	33252.	56046.	90099.	119026.	142912.	154002.	154973.	155000.
515731	578871.	67887.	326709	368249.	402090.	492564.	561704.	599473.	627222.	635349.	636100.
515831	39175.	14136.	0	0.	3741.	15823.	33882.	43922.	50282.	51373.	52400.
509431	155048.	47098.	7929	34773.	52982.	78119.	133749.	169582.	193933.	198135.	206550.
516531	172869.	56590.	0	12605.	41255.	86851.	147592.	190723.	218158.	222734.	225400.
515931	39649.	17934.	0	0.	5489.	12827.	26026.	43460.	57065.	59345.	59400.
516031	364591.	121536.	0	0.	41211.	188121.	337634.	409932.	455051.	457600.	457600.
516131	181097.	70449.	0	0.	0.	35556.	163356.	209355.	233570.	235670.	235700.
516231	27076.	11600.	0	0.	0.	7198.	20538.	32134.	36603.	37070.	37100.
516331	52377.	18256.	0	0.	7753.	23733.	47347.	61214.	65495.	65500.	65500.
516431	128378.	37944.	0	19129.	50989.	68738.	110474.	141525.	160110.	160110.	160110.
Total	2505624.	521846.	883151	972583.	1275247.	1694851.	2306754.	2673330.	2894579.	2979372.	3015596.

Table 7.3 Flow Frequency of Monthly Regulated Flow for Scenarios 5.01 and 5.19, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.01, Monthly Time Step											
LRCA58	82940.7	158828.	0.0	570.0	1189.9	1229.8	4009.7	17633.	86682.	236627.	1399448.
BRBR59	243301.9	438021.	0.0	1248.7	5463.0	9621.5	24289.0	71037.	263939.	656599.	4301499.
BRHE68	340324.4	536578.	0.0	9553.8	14834.8	21998.3	46765.9	116411.	432665.	958484.	5236145.
BRRI70	371315.4	564966.	0.0	14122.6	20314.9	28301.3	53914.7	133546.	461447.	1040992.	5633058.
BRGM73	340791.5	583988.	0.0	0.0	0.0	0.0	2461.5	85479.	447943.	1011849.	5689012.
515531	32457.3	111939.	0.0	0.0	0.0	0.0	0.0	0.	10993.	81423.	1599164.
515631	49124.2	151550.	0.0	0.0	0.0	0.0	0.0	1454.	28433.	133780.	2450764.
515731	64247.5	173159.	0.0	0.0	0.0	0.0	1676.0	9269.	42152.	170256.	2728846.
515831	4409.4	10931.	27.8	27.8	29.8	29.8	30.8	31.	2245.	15453.	100103.
509431	19986.8	50253.	0.0	0.0	0.0	0.0	0.0	0.	14515.	66688.	529065.
516531	11344.5	27698.	0.0	0.0	0.0	0.0	0.0	0.	2764.	45576.	215300.
515931	8450.2	26941.	0.0	0.0	0.0	0.0	0.0	37.	3137.	21842.	320839.
516031	27991.3	69704.	0.0	0.0	0.0	0.0	0.0	1498.	20497.	83931.	549161.
516131	12327.7	31839.	0.0	0.0	0.0	0.0	0.0	222.	7661.	39269.	305240.
516231	3513.9	7909.	0.0	0.0	0.0	0.0	0.0	150.	2699.	12223.	73211.
516331	11948.4	23648.	0.0	0.0	0.0	0.0	0.0	1730.	12464.	39255.	208215.
516431	13203.3	30339.	0.0	0.0	0.0	0.0	0.0	0.	7106.	52326.	247496.
Scenario 5.19, Daily Time Step											
LRCA58	84256.4	153711.	0.0	703.3	1697.5	3146.4	8263.6	24739.	90632.	222434.	1398540.
BRBR59	248215.8	417737.	83.9	5428.1	9790.4	14808.5	31146.5	88327.	272039.	644857.	3759036.
BRHE68	345391.3	511152.	421.8	12098.0	19861.9	29458.7	57574.0	141279.	430385.	945890.	4189584.
BRRI70	376096.4	536515.	0.0	16793.0	24526.3	35294.5	62480.5	152778.	476539.	1031138.	4300738.
BRGM73	347085.8	555342.	0.0	4.2	271.0	2421.0	19455.9	115201.	445522.	1011021.	4397198.
515531	35301.2	109611.	0.0	0.0	4.7	243.1	844.1	3168.	19605.	84184.	1551342.
515631	51852.3	145631.	1.6	125.6	286.6	718.8	1887.3	8145.	36191.	137894.	2313415.
515731	67604.5	164442.	0.0	275.2	1252.9	2442.5	6100.9	16748.	51149.	170177.	2513149.
515831	4520.3	10711.	0.0	27.8	29.8	30.8	35.8	317.	2601.	15153.	100103.
509431	19836.4	47742.	0.0	0.0	0.0	2.2	70.6	1059.	13856.	63387.	517341.
516531	11585.3	26215.	0.0	0.0	4.9	31.8	155.6	925.	6332.	43909.	214430.
515931	8865.2	25627.	0.0	0.0	0.1	39.7	342.7	1238.	4650.	21895.	305303.
516031	28608.4	65716.	0.0	0.0	0.2	332.2	1982.2	4786.	20591.	79546.	538777.
516131	12720.8	30357.	0.0	8.3	31.7	85.6	476.6	1869.	8129.	36899.	274448.
516231	3576.2	7746.	0.0	0.0	1.1	14.0	99.2	468.	2431.	12142.	70078.
516331	12108.0	23197.	0.0	2.5	59.0	192.6	656.8	2462.	11941.	38563.	198742.
516431	13376.2	30062.	0.0	0.0	0.0	1.4	65.6	498.	7610.	52564.	247232.

Table 7.4 Flow Frequency of Monthly Unappropriated Flow for Scenarios 5.01 and 5.19, ac-ft per month

CONTROL POINT	MEAN	STANDARD DEVIATION	% OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	98%	95%	90%	75%	50%	25%	10%	MAXIMUM
Scenario 5.01, Monthly Time Step											
LRCA58	66752.5	153118.	0.0	0.0	0.0	0.0	0.0	0.	63569.	205292.	1392117.
BRBR59	182163.3	414906.	0.0	0.0	0.0	0.0	0.0	0.	183351.	549365.	4243700.
BRHE68	223506.3	481078.	0.0	0.0	0.0	0.0	0.0	1704.	228048.	746384.	4963221.
BRRI70	281299.3	528959.	0.0	0.0	0.0	0.0	0.0	36245.	365311.	894372.	5304625.
BRGM73	340791.5	583988.	0.0	0.0	0.0	0.0	2461.5	85479.	447943.	1011849.	5689012.
515531	24221.8	103187.	0.0	0.0	0.0	0.0	0.0	0.	0.	49440.	1599164.
515631	39686.4	145920.	0.0	0.0	0.0	0.0	0.0	0.	7273.	103874.	2450764.
515731	52513.3	170590.	0.0	0.0	0.0	0.0	0.0	0.	18716.	156654.	2728846.
515831	4022.1	10908.	0.0	0.0	0.0	0.0	0.0	0.	336.	15014.	100072.
509431	18965.4	50455.	0.0	0.0	0.0	0.0	0.0	0.	8357.	66688.	529065.
516531	10834.2	27298.	0.0	0.0	0.0	0.0	0.0	0.	701.	43874.	215300.
515931	6613.4	25523.	0.0	0.0	0.0	0.0	0.0	0.	0.	12384.	259583.
516031	25473.8	69409.	0.0	0.0	0.0	0.0	0.0	0.	7041.	81885.	549161.
516131	11447.6	31700.	0.0	0.0	0.0	0.0	0.0	0.	1462.	39269.	305240.
516231	3221.7	7907.	0.0	0.0	0.0	0.0	0.0	0.	1551.	11938.	73211.
516331	10778.7	23910.	0.0	0.0	0.0	0.0	0.0	0.	10993.	38739.	208215.
516431	12887.4	30275.	0.0	0.0	0.0	0.0	0.0	0.	6198.	52326.	247496.
Scenario 5.19, Daily Time Step											
LRCA58	54761.2	122329.	0.0	0.0	0.0	0.0	0.0	3133.	50374.	172089.	1307873.
BRBR59	153299.3	317026.	0.0	0.0	0.0	0.0	676.0	21881.	159319.	469537.	2969544.
BRHE68	233252.3	425867.	0.0	0.0	0.0	0.0	1789.0	41927.	294610.	729248.	3568162.
BRRI70	285323.5	491231.	0.0	0.0	0.0	0.0	5047.8	71744.	366088.	844328.	3985426.
BRGM73	347085.8	555342.	0.0	4.2	271.0	2421.0	19455.9	115201.	445522.	1011021.	4397198.
515531	15140.0	73052.	0.0	0.0	0.0	0.0	0.0	0.	155.	29050.	1372427.
515631	28421.3	109241.	0.0	0.0	0.0	0.0	0.0	101.	9139.	63873.	1906246.
515731	39446.1	131681.	0.0	0.0	0.0	0.0	0.0	841.	15237.	110829.	2149806.
515831	2806.8	7921.	0.0	0.0	0.0	0.0	0.0	5.	338.	9051.	53482.
509431	13563.0	36692.	0.0	0.0	0.0	0.0	0.0	23.	4777.	45409.	305691.
516531	4780.1	12680.	0.0	0.0	0.0	0.0	0.0	2.	396.	16738.	81342.
515931	3294.8	13067.	0.0	0.0	0.0	0.0	0.0	1.	205.	5412.	128545.
516031	19532.8	54295.	0.0	0.0	0.0	0.0	0.0	108.	4732.	64715.	501930.
516131	8530.9	24337.	0.0	0.0	0.0	0.0	0.0	0.	1184.	28295.	250061.
516231	2775.0	7026.	0.0	0.0	0.0	0.0	0.0	2.	922.	10274.	65300.
516331	9015.8	20564.	0.0	0.0	0.0	0.0	0.0	25.	7649.	30660.	196672.
516431	12107.3	28192.	0.0	0.0	0.0	0.0	0.0	0.	6460.	48616.	247127.

Table 7.5 Reliability Summaries of Water Rights at BRA Reservoirs for Scenarios 5.01 and 5.19

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	% OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING % OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
Scenario 5.01, Monthly Time Step											
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18886.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	94630.8	3230.14	91.67	96.59	91.7	91.8	92.0	92.2	99.1	99.7	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	438.04	98.85	99.35	98.9	99.0	99.1	99.3	99.3	99.3	99.6
516231	13610.0	237.10	97.99	98.26	98.0	98.1	98.1	98.1	98.3	98.3	98.4
516331	19840.0	66.35	99.43	99.67	99.4	99.4	99.4	99.6	99.6	99.6	99.6
516431	48000.0	51.99	99.71	99.89	99.7	99.7	99.7	99.7	99.9	99.9	100.0
Total	769082.2	4023.66		99.48							
Scenario 5.19, Daily Time Step											
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64855.1	302.05	99.43	99.53	99.4	99.4	99.4	99.4	99.7	99.9	100.0
515731	17973.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13938.4	482.69	96.12	96.54	96.1	96.1	96.1	96.1	96.4	97.0	97.4
509431	98033.9	4877.71	88.79	95.02	88.8	89.1	89.4	90.4	98.1	99.4	100.0
516531	65345.2	974.27	98.42	98.51	98.4	98.4	98.6	98.7	98.9	98.9	99.1
515931	20036.7	816.64	96.70	95.92	96.7	96.8	97.0	97.3	97.7	98.0	98.4
516031	112552.6	2628.22	96.84	97.66	96.8	96.8	97.0	97.0	97.4	97.8	98.4
516131	68142.1	4096.48	93.25	93.99	93.2	93.2	93.2	93.4	93.8	94.8	96.6
516231	13681.2	832.90	93.53	93.91	93.5	93.5	93.5	93.5	93.7	94.3	96.3
516331	19980.5	648.94	96.84	96.75	96.8	96.8	96.8	96.8	97.0	97.6	98.1
516431	48296.8	687.12	98.71	98.58	98.7	98.7	98.7	98.7	98.9	99.0	99.1
Total	773586.0	16347.05		97.89							

Table 7.6 Mean Shortage and Volume Reliability for Selected Run-of-river Water Rights for Scenarios 5.01 and 5.19

Selected Water Rights	Target Diversion ac-ft per year	Mean Shortage, ac-ft per year		Volume Reliability, %	
		5.01	5.19	5.01	5.19
Dec. 31, 1929, and Senior, all uses	120,722	2,257	5,148	98.1	95.7
Jan. 1, 1930, to Dec. 31, 1939, all uses	75,550	1,949	5,300	97.4	93.0
Jan. 1, 1940, to Dec. 31, 1949, all uses	191,981	14,924	27,939	92.2	85.4
Jan. 1, 1950, to Dec. 31, 1959, all uses	112,238	12,862	19,819	88.5	82.3
Jan. 1, 1960, to Dec. 31, 1969, all uses	125,777	19,856	25,467	84.2	79.8
Jan. 1, 1970, to Dec. 31, 1979, all uses	4,692	1,137	1,523	75.8	67.5
Jan. 1, 1980, and Junior, municipal use	75,000	10,019	17,575	86.6	76.6
Jan. 1, 1980, and Junior, non-municipal use	84,261	26,423	25,643	68.6	69.6
All Selected Water Rights	790,221	89,427	128,414	88.7	83.7

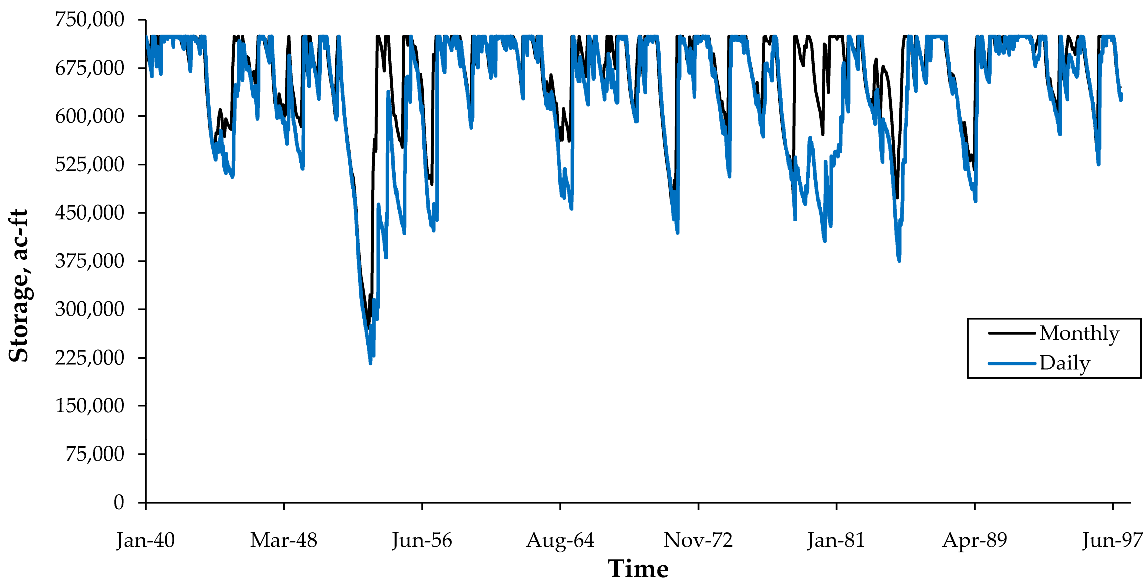

Figure 7.2 Monthly versus Daily Simulated Storage in Possum Kingdom Lake

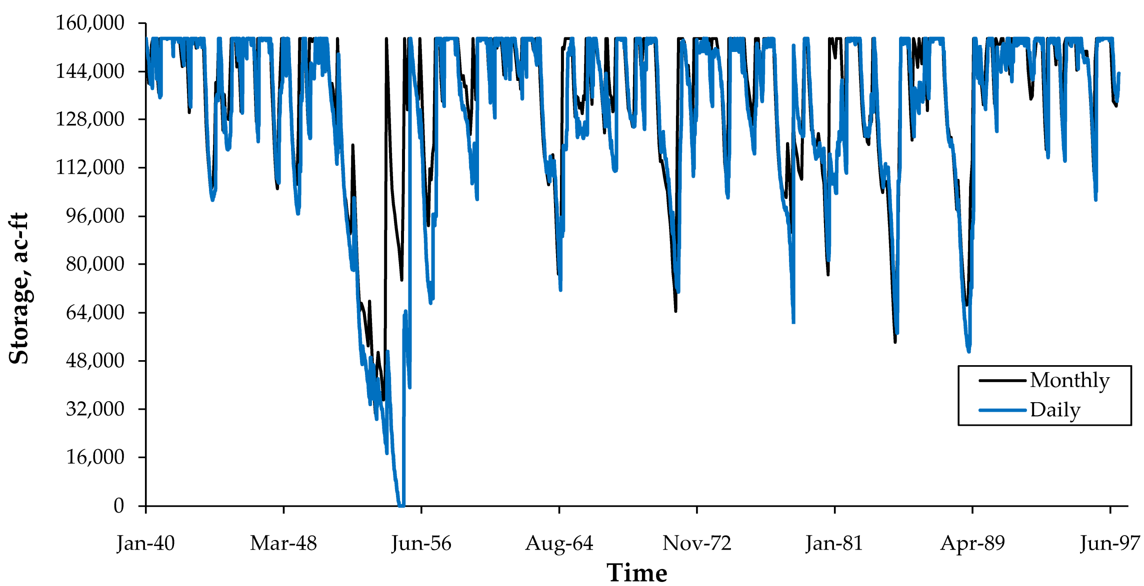

Figure 7.3 Monthly versus Daily Simulated Storage in Granbury Lake

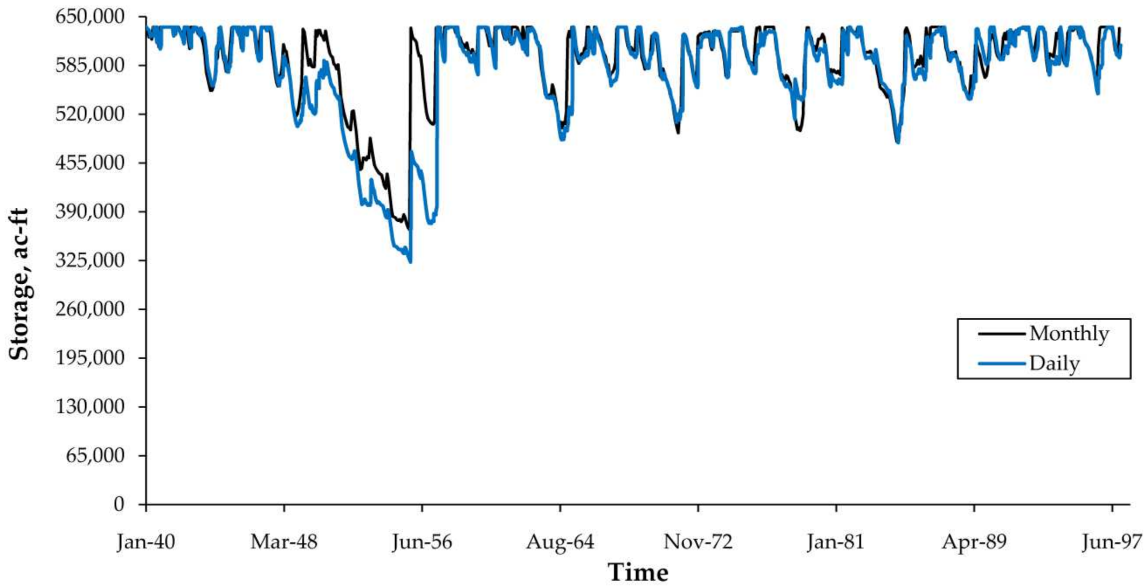

Figure 7.4 Monthly versus Daily Simulated Storage in Whitney Lake

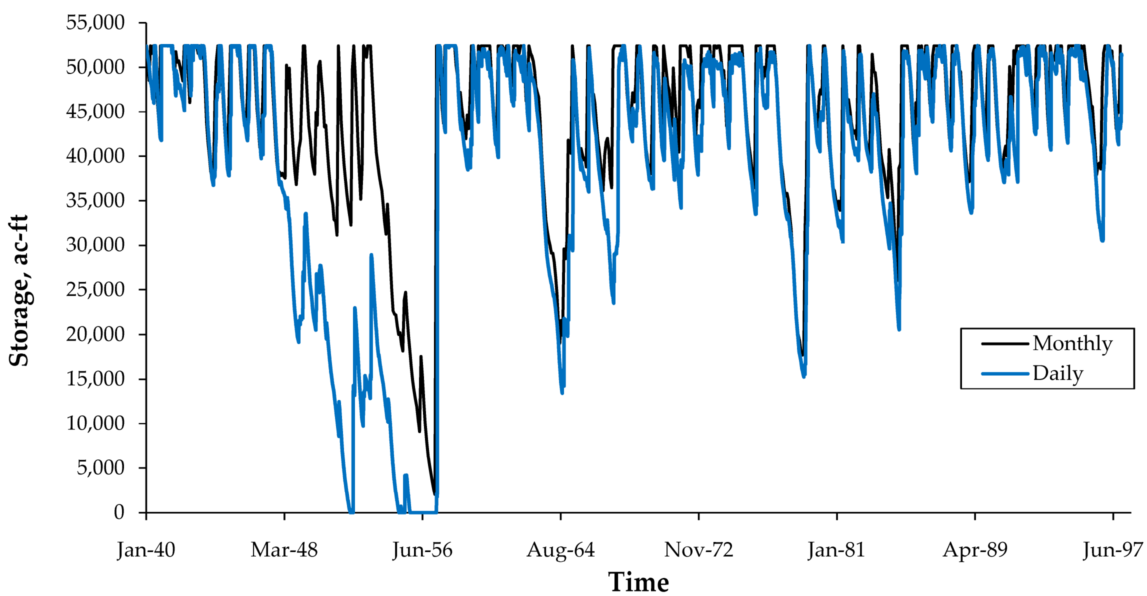

Figure 7.5 Monthly versus Daily Simulated Storage in Aquilla Lake

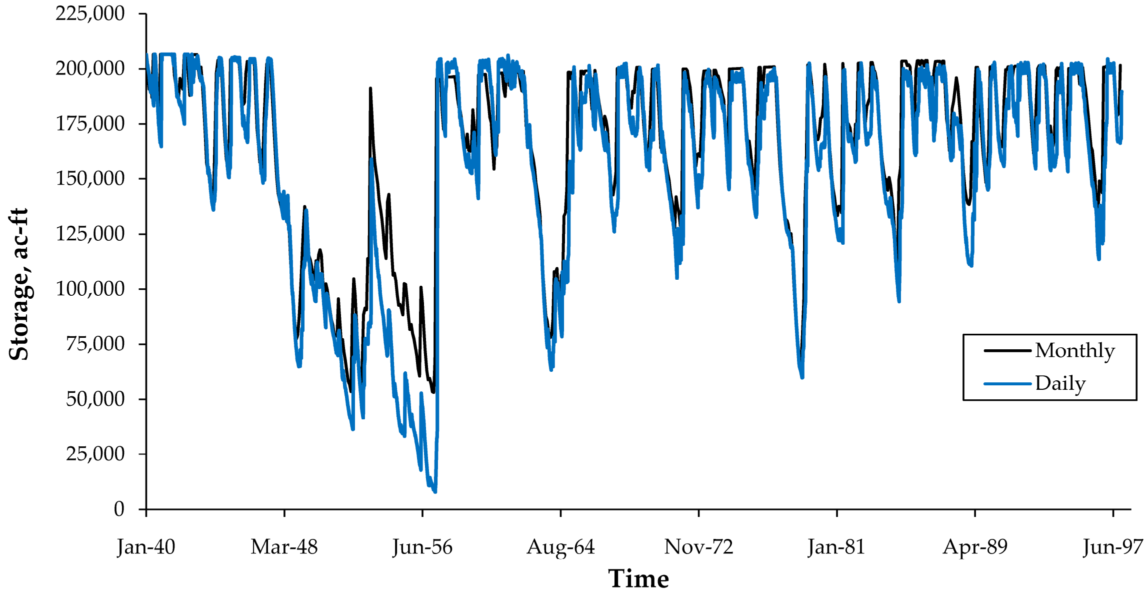

Figure 7.6 Monthly versus Daily Simulated Storage in Waco Lake

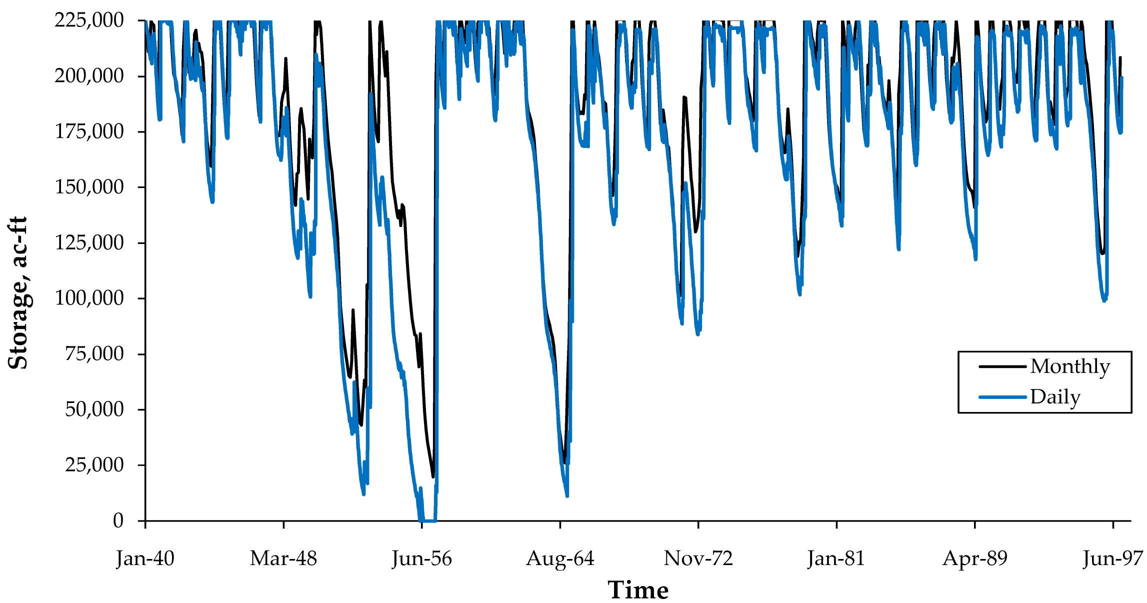

Figure 7.7 Monthly versus Daily Simulated Storage in Limestone Lake

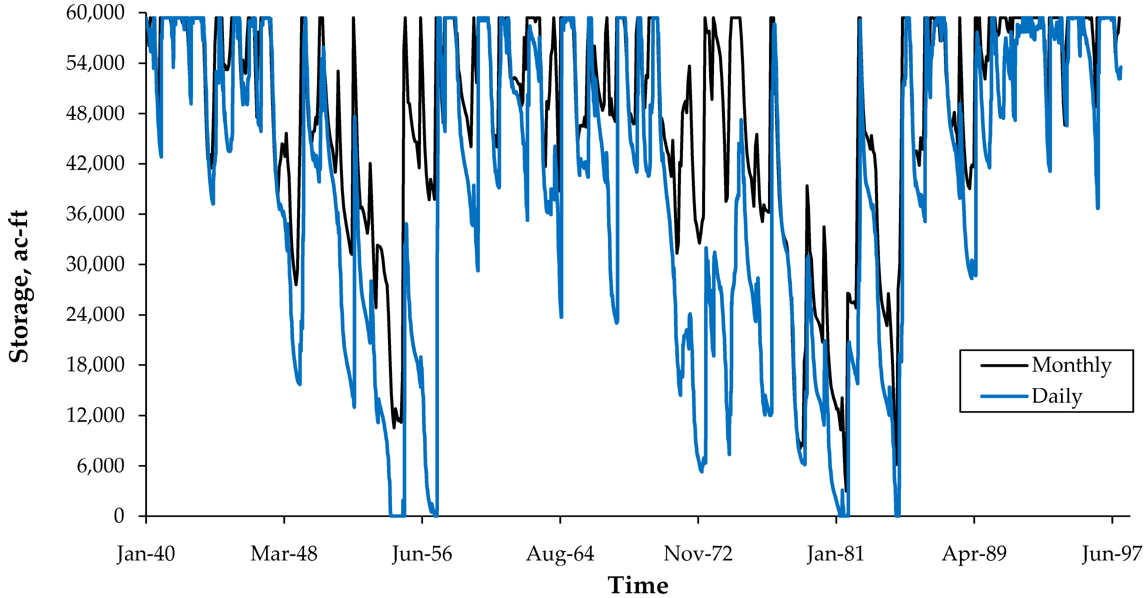

Figure 7.8 Monthly versus Daily Simulated Storage in Proctor Lake

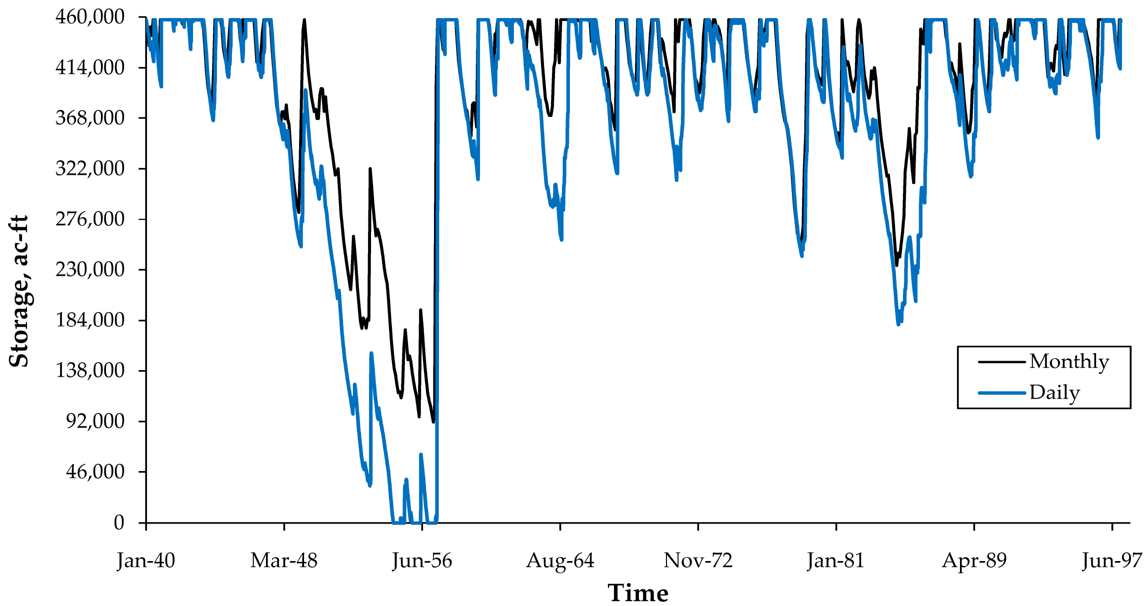

Figure 7.9 Monthly versus Daily Simulated Storage in Belton Lake

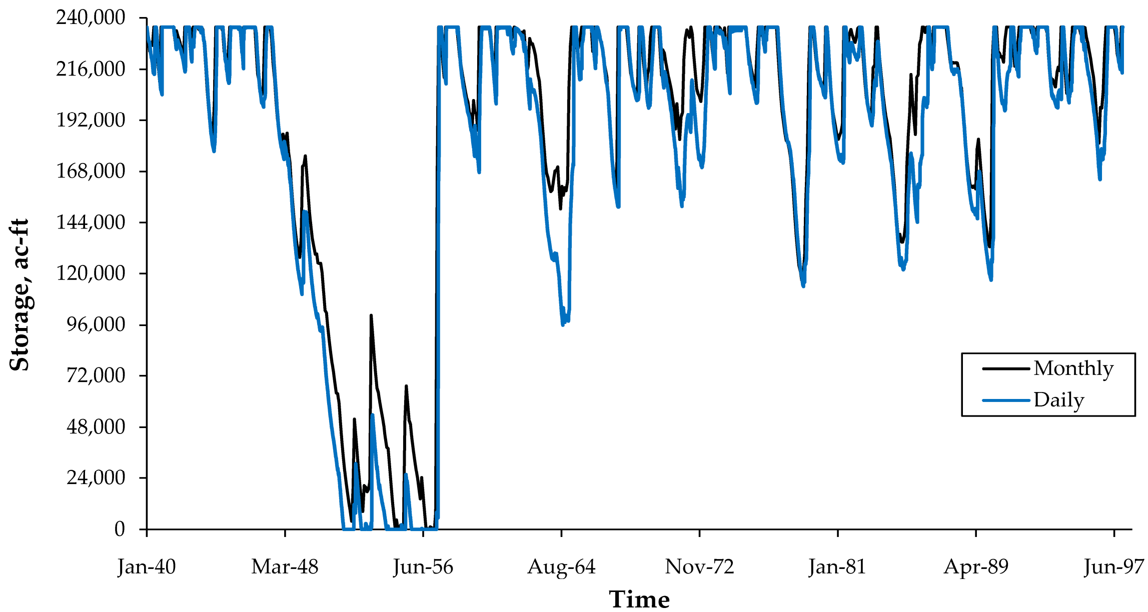

Figure 7.10 Monthly versus Daily Simulated Storage in Stillhouse Hollow Lake

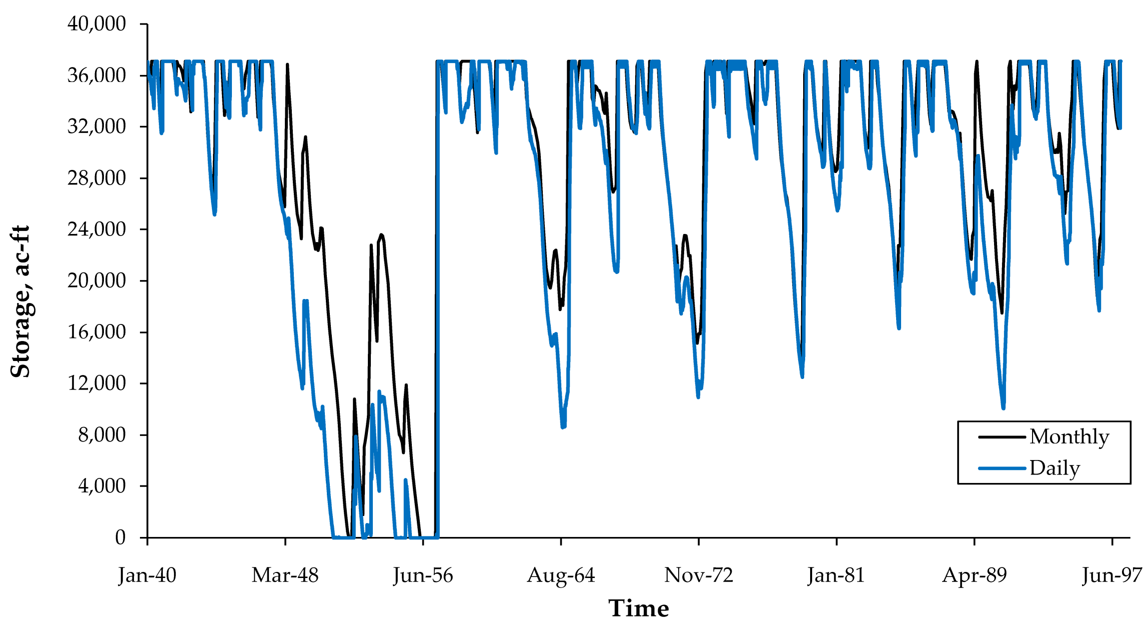

Figure 7.11 Monthly versus Daily Simulated Storage in Georgetown Lake

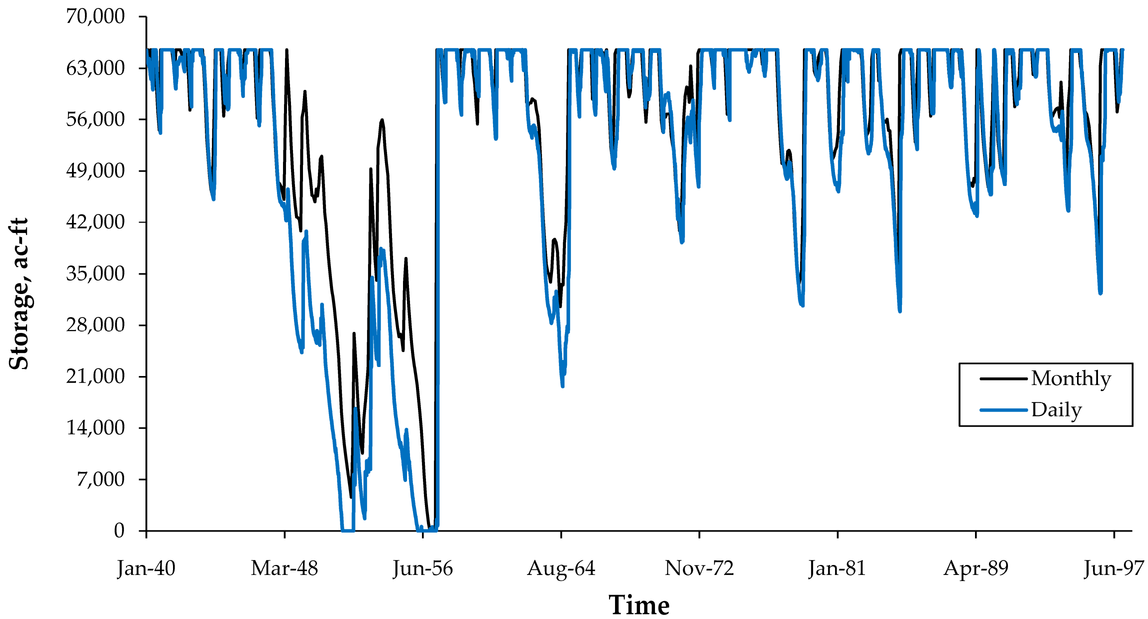

Figure 7.12 Monthly versus Daily Simulated Storage in Granger Lake

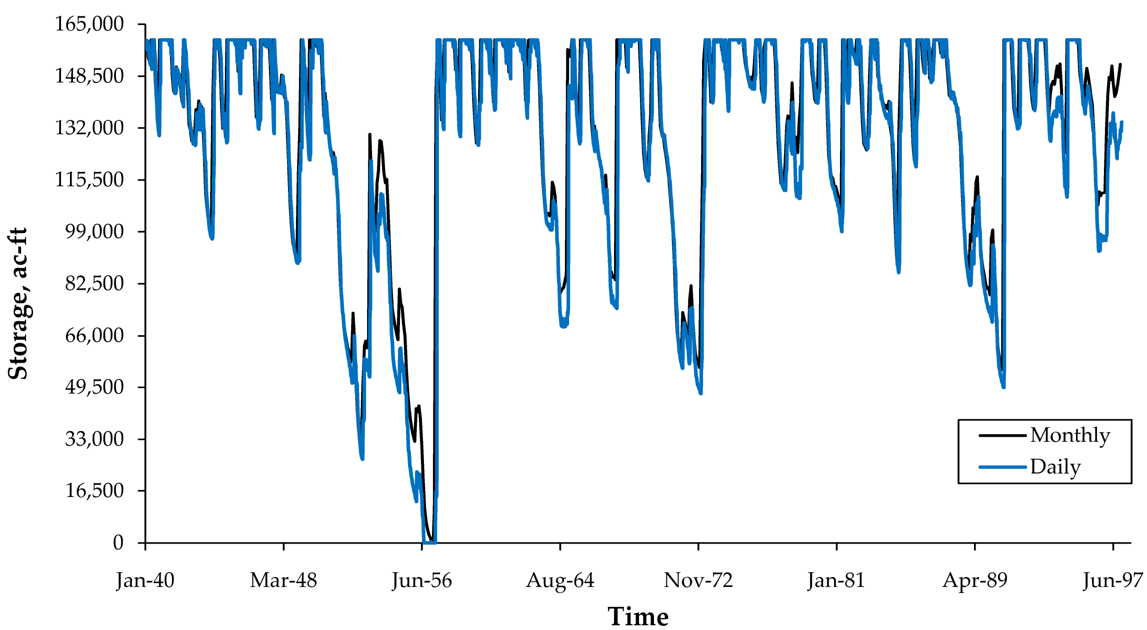

Figure 7.13 Monthly versus Daily Simulated Storage in Somerville Lake

7.3 Flood Control Simulations

The daily time step features of SIMD facilitate modeling reservoir operations for flood control. Relatively small computational time steps are required to accurately model flood control operations due to the great fluctuations in flow rates over short time spans that typically occur during flood events. SIMD uses a day as the smallest time step for simulation that can be used for modeling flood control operations of large river and reservoir systems. Smaller systems may require smaller time steps.

Flood control reservoir operations are treated as a type of water right in SIMD. Within WRAP, a water right is a set of water control requirements and associated reservoir facilities and operating rules. Flood control rights are activated by FR records and are simulated along with all other water rights activated by WR and IF records. The same reservoir may have any number of WR or IF record rights with associated WS and OR records, and any number of FR record flood control rights.

Forecasted regulated flow at the location of the FF record rights is used in conjunction with the FR record operating rules to begin impounding streamflow in controlled flood control storage. Forecasting can also reduce the amount of water released from controlled flood control storage. By adopting a forecast period on the FF record rights, the SIMD modeling approach generally provides a conservatively higher estimate of the amount of water to be stored in controlled flood control storage to reduce to the extent possible the amount of regulated flow at the location of the FF record rights.

The objective of Chapter VI was to examine the performance of the SIMD flood control features in reducing regulated flow below maximum allowable release rates at the flood control reservoirs and the maximum allowable discharge rates at downstream flood flow gaging locations. Flood control input records were developed for SIMD using USACE flood control limits and flood control pool elevation, capacity, and area data. Regulated flow forecasting periods were varied in SIMD at the downstream FF record locations in the model. Simulation results were compared in terms of the effect on regulated flood flow frequency and flood storage frequency.

Flood control in SIMD was shown to be effective in reducing regulated flows below flood flow limits for the Brazos WAM case study. The following guidelines draw upon the construction of the flood control records for the DAT file and the simulation results of the case study. Other river basins may have unique flood control situations that were not represented in the Brazos WAM case study.

7.3.1 Disaggregation of Monthly Naturalized Flow

Flood control simulation deals with infrequent events of high streamflow magnitude. Actual unregulated or naturalized flow patterns provided on the DF records can produce the correct magnitude, frequency, and timing of the flood events. It is unlikely that using the uniform, linear interpolation, or variability adjustment methods of disaggregating monthly naturalized flow into daily flow will generate realistic flow rates or flow frequencies for simulating flood control. The uniform method of disaggregation is equivalent to simulating with a monthly average flow. High flow pulses and overbanking flood events are not well represented with monthly average flows. The linear interpolation and variability adjustment methods introduce more variability to the daily hydrograph. However, flow averaging with these disaggregation methods will tend to underestimate the extreme variability and the upstream-to-downstream timing of real-world flood events.

SIMD allows DF records to be repeated when the DF record period is shorter than the monthly naturalized period of record set by the JD record. Repeating a sequence of DF records over a longer period of record may also result in inaccuracies for simulating flood control. A daily flow pattern with a fairly uniform hydrograph could be paired with a very large naturalized monthly flow. The resulting disaggregated daily naturalized flows for the simulation may not contain a daily flow within that month of sufficient magnitude to trigger flood control operations. Conversely, a daily flow pattern with a highly variable hydrograph could be paired with a low naturalized monthly flow volume. The resulting disaggregated daily naturalized flows for the simulation could contain a daily peak flow with a flow magnitude exceeding flood limits when the real-world flows were otherwise characterized by a hydrograph typical of low variability flows.

The smallest time step available in SIMD is 1 day. Daily flows represent the entire volume of flow that passes through the control point for a particular day. Real-world flood control operations are typically triggered by measurements or forecasts of instantaneous flow rates. For example, the maximum allowable discharge at the Richmond gage on the main stem of the Brazos River, as set by the USACE, is 60,000 cubic feet per second. In the Chapter VI case study, the maximum allowable discharge at Richmond was computed by converting 60,000 cubic feet per second into a daily volume of 119,008.3 ac-ft per day. This daily volume was used for the daily target of the FF record at Richmond. The relationship of daily flow volume to daily maximum instantaneous flow, particularly for the rising limb of the hydrograph, may require examination prior to establishing daily targets for the FF records. In some instances, the use of daily time steps may mask the achievement of instantaneous flow rates above flood limits. Small streams or basins characterized by extreme flash flow response could have flood conditions develop and dissipate in less than 1 day.

7.3.2 JU, FR, and FF Record Parameter Options

The JU record field 7 parameter, FRMETH, governs whether the changes to flow of the flood control pools are placed within the priority sequence or before the priority sequence. If flood control pools are the most junior water rights being simulated, placing their respective changes to flow at their junior priority will result in no affect on the WR and IF record rights, with the exception of increases to reservoir storage. FR record flood control reservoirs can fill conservation storage when flood control streamflow depletions occur and the conservation pool level is less than full. Placing the changes to flow made by flood control pools before the priority sequence can affect the water availability of all WR and IF record rights in the basin. The Chapter VI case study used the option to place the changes to flow at the beginning of the priority sequence so the full effect on water availability could be measured.

The amount of flood control streamflow depletions is limited by the remaining storage capacity in the reservoir or the computation of water availability. The FR record field 7 parameter, FCDEP, can change the computation of water availability. The default FCDEP option is to proceed with the conventional water availability method of examining the water availability values at the control point of the depletion and all downstream control points. The alternative FCDEP option is to ignore all downstream control points in the conventional water availability method. The alternative option allows maximum flood control streamflow depletions to be made at the expense of potentially depleting streamflows that have already been appropriated by downstream water rights. However, downstream water rights will benefit from the flood control releases being made immediately after flooding conditions subside. Real-world flood control operations will be best replicated in SIMD with the alternative FCDEP option to ignore downstream control points in determining water availability for streamflow depletions. The Chapter VI case study used the FCDEP alternative water availability option.

Flood control dams typically have a maximum allowable release rate. Releases through the dam's outlet structures are not allowed to exceed the maximum allowable release rate except during emergency operations. The FR record field 8 parameter, FCMAX, sets a maximum release rate for the controlled flood control storage defined by FR record fields 9, 10, and 11. In the Chapter VI case study, several flood control reservoirs had differing maximum release rates with respect to the state of storage as a percentage of the flood control pool capacity. Multiple FR records can be used for the same flood control pool in SIMD. Each FR record can have a different value of FCMAX to model the increase in maximum allowable release with increasing storage contents.

A forecast period can be specified by the FF record field 5 parameter, FPERIOD. If a forecast period is selected, values of regulated flow at the FF record location are recorded during the forecast simulation. No releases from controlled flood control storage are made during the forecast simulation. Uncontrolled flood control releases may occur during the current day or forecast simulation. Forecasting can improve the ability of flood control reservoirs to mitigate downstream flooding conditions by allowing streamflow depletions to occur by the flood control reservoir prior to downstream flooding. The time delay effects of routing necessitate the use of forecasting. However, forecasting can result in increased storage contents in the flood control reservoirs via unnecessarily premature streamflow depletions or unnecessarily extended periods of withholding releases. The Chapter VI case study varied the forecast periods on the downstream FF record rights. Long forecasting periods degraded the performance of the flood control pools by filling the reservoirs to the top of flood control more often than necessary. A forecast period with a maximum of 3 days for the most downstream FF record rights was chosen. Forecast period selection should be carried out on a case-by-case basis for each basin.

7.3.3 Flood Control Systems

All flood control pools with the same priority are treated as components of a multiple-reservoir system. Each FR record right has a priority for storing flood flows and a separate priority for the subsequent release of the stored flood waters. If multiple reservoirs share the same storage priority, these reservoirs are treated as a multiple-reservoir system in making storage decisions. Likewise, if multiple reservoirs share the same release priority, these reservoirs are treated as a multiple-reservoir system in making release decisions. At the beginning of each time step, the ordering of reservoirs in a multiple-reservoir system for purposes of operating decisions is based on a ranking index. System reservoirs with a greater available capacity as a percentage of the total capacity are allowed to impound prior to other system reservoirs. System reservoirs with a lower available capacity as a percentage of the total capacity are allowed to release prior to other system reservoirs.

System operation of flood control reservoirs was applied in the Chapter VI case study to Lakes Whitney and Waco and to Lakes Belton and Stillhouse. These systems were created to improve the ability of the reservoirs in managing flood conditions at their common and nearby downstream flood gages. Lakes Whitney and Waco are upstream of the flood flow gage on the main stem of the Brazos River at Waco. Aquilla Lake is also upstream of the Waco gage but was not selected for system operation due to its small relative flood control capacity relative to Lakes Whitney and Waco. However, Aquilla Lake could be included if so desired. Lakes Belton and Stillhouse are upstream of the flood flow gage on the Little River near the community of Little River. Proctor Lake is also upstream of the Little River gage. However, Proctor Lake was not selected for system operation due a much longer distance upstream from the Little River gage.

Multiple FR records per reservoir were created for the Whitney-Waco and Belton-Stillhouse flood control systems and can be seen in Table 4.15. Each FR record created for each reservoir was assigned the same storage and release priority as a corresponding FR record in the other system reservoir. The records create pools of equal percentages of the total flood control storage capacity and not pools of equal absolute volume. The records were assigned successively junior priorities. Using multiple FR records per system reservoir improves the likelihood that the reservoirs will fill and drawdown on an equal percentage basis. When a flood event is indicated by the common downstream FF record right, each reservoir in the system will fill one pool in the system before proceeding to the consideration of filling the next pool. After flood conditions have subsided, each reservoir in the system will release from the top-most pool containing storage before proceeding to the next pool or until downstream regulated flow capacity has been exhausted for that day.

The priority dates on the FR records can be arranged to allow any sequence of storing or releasing from non-system flood control pools. In the Chapter VI case study, storage priorities were arranged to allow for a general upstream-to-downstream order of consideration. Release priorities were arranged to allow for a general downstream-to-upstream order of consideration. The choice of ordering reflects an operational policy to retain flood waters higher in the basin when possible. Flood control capacity lower in the basin is generally reserved until needed.

7.3.4 Water Availability

Flood control in SIMD affects water availability for WR and IF record rights. Flood control pools, when added on top of an existing conservation pool, increase the storage capacity of the underlying reservoir. Flood control rights divert streamflow, and conservation storage is filled if the conservation pool is not already full. Therefore, water right demands on conservation storage can potentially be met from water stored during junior flood control operations. Flood control operations can also affect water availability in SIMD through flood control releases if the JU record parameter FRMETH is set to allow flood control depletions and releases to be routed prior to the priority sequence. Flood control releases may occur for several days or weeks after a major flood event. These releases are placed into the stream and become part of the available water for any water right in the basin.

Conservation pools that experience periods of zero storage contents when modeled without a flood control pool can potentially experience fewer or no days of zero storage contents when a flood control pool is added to the reservoir. Furthermore, the sequence in which flood control reservoirs are activated during drought conditions can affect the amount of water stored in a particular reservoir. Experimentation with flood control priority numbers may result in different outcomes for drought period conservation storage. Figure 6.20 showed the daily time series of storages for Proctor Lake. The 1950s' drought resulted in many days of zero end-of-day storage contents in Proctor when modeled without a flood control pool. The addition of flood control above the conservation pool eliminated the days of zero storage contents during the 1950s' drought. Flood control for Proctor was modeled with the alternative water availability option, FCDEP. Modeling flood control subject to the conventional water availability computation may not result in the same increase in storage for Proctor during the 1950s' drought.

Run-of-river rights below flood control reservoirs may experience shortages when flood control reservoirs impound flood waters upstream. The choice of FCDEP on the FR records, however, may change whether the downstream water rights experience shortage. Storing flood water typically occurs over a fewer number of days than releasing water completely from flood control storage after the flood event. Downstream run-of-river rights may experience an increase in water availability as the flood control reservoir makes releases from flood control storage for several days to potentially several weeks after the flood event.

7.3.5 Regulated Flows

Table 6.10 presented the daily regulated flow frequency for simulations with and without flood control. Figures 6.2 through 6.16 showed the time series of daily regulated flow for the same control points in Table 6.10. Flood control had a significant effect on peak regulated flows above the various flood control discharge limits. Regulated flows corresponding to the magnitude of high flow pulses and overbanking flows would also likely be affected with the inclusion of flood control in the simulation.

High flow event duration and volume were also affected by flood control. Table 6.10 and Figures 6.26 through 6.31 also illustrated that flood control can increase the magnitude and duration of regulated flows at flow-frequencies below the peak discharge limits and above the 50% exceedance. Though flood control reduces high magnitude flow events, the subsequent releases from flood control at lower flow rates will contribute to flows that may be characterized as high baseflow levels to bank full flow events.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Water rights in Texas are administered according to the doctrine of prior appropriation, which is based on the tenet of "first in time, first in right" (Wurbs 1995). Water rights authorized first are known as senior rights. Water rights authorized at a later date are known as junior rights. The relative ranking of water rights according to their time of authorization is intended to protect more senior rights from impairment by newer or more recently authorized rights.

Quantitative estimates of available water for new water right applications or amendments to existing applications are made through the use of the WAM System by the TCEQ as a constituent of the larger process for evaluating new surface water rights. The generalized WRAP computer model adheres to the doctrine of prior appropriation in the simulation of water rights. WRAP, the TCEQ-developed basin-specific input files, the GIS datasets, and the accompanying auxiliary programs form the components of the TCEQ WAM.

WRAP is a generalized surface water allocation model and can be applied to any river basin or particular reservoir or water right system. Input files particular to Texas river basins are developed for the TCEQ WAM. WRAP-SIM is the simulation program within the WRAP suite of programs. SIM simulates water resources management of a single basin or multiple basins using a priority order based algorithm through a period of homogenous or naturalized hydrology. SIM utilizes a monthly time step to represent hydrology and water management features in the model.

The objective of this research was the development of modeling capabilities that address key daily time step issues in a flexible and robust manner while still meeting the requirements of a priority-based modeling paradigm. The key modeling issues that were identified as being relevant to daily time step modeling but are otherwise not considered with monthly simulations include:

- disaggregating monthly naturalized flows into daily flows,
- routing changes to flow through the stream network,
- reducing impacts to water availability in a priority-order based water right system through the use of streamflow forecasting,
- distributing water right targets from monthly to daily amounts, and
- integrating flood control reservoir operations into the existing conservation reservoir only modeling framework.

The purpose of the case study was to present the modeling capabilities developed by this research in the context of a modeling implementation and to explore the various alternative configurations and parameterizations that are possible with SIMD. As illustrated by Tables 1.1 and 1.2, the TCEQ WAM System is extensive in terms of the number of water management features represented as well as the number of time steps performed during the simulation. The Bwam dataset is the largest in terms of the number of control points and one of the larger in terms of total water management features represented in the model. Meeting the needs of a highly detailed water management modeling dataset with daily time step simulation capabilities provided a rigorous research and development challenge. The Bwam modeling dataset used in the case study also provided an exceptional opportunity to examine the effects of modeling time step on a large number of water management features across diverse physical streamflow settings and through a period of record representing a vast majority of the possible streamflow conditions.

The case study illustrated that streamflow variability is the single greatest factor that affects the simulation of water availability between monthly and daily simulations. The monthly naturalized flow volume was the same in all monthly and daily time step simulations presented in the case study. However, simulated regulated flow, unappropriated flow, water right reliability, and reservoir storage could be substantially different in a daily simulation when compared to the monthly simulation. The principal factor determining the difference in simulation outcome was the choice of monthly to daily flow disaggregation.

Uniformly distributing monthly flows by the number of days in the month produced daily simulation results nearly identical to a monthly time step simulation. Disaggregating monthly naturalized flow to replicate realistic daily naturalized or unregulated flow patterns, however, introduced intra-month flow variability and upstream-to-downstream travel time as represented in the hydrographs at successive control points in the stream network. Routing methods were developed for SIMD to cascade changes to streamflow downstream in synchronization with the underlying flow events. Changes to flow from junior rights could affect water availability for senior rights until the changes exited the stream network. Flow forecasting was a method developed for SIMD to reduce impacts to the priority order based system for allocating water as a result of the effects of routing. In addition to routing, realistic daily flow patterns created intra-month flow variability. Water rights were modeled as seeking to deplete streamflow to meet a monthly target demand. Non-uniform daily target building and intra-month shortage recovery were developed for SIMD as an option to better match demands with variable water availability. Finally, realistic daily flow patterns allowed for the representation of flood flow events. Flood control reservoirs and flood flow gages were developed for SIMD and allowed the model to represent real-world flood control operations within the water supply framework of WRAP.

The following conclusions can be drawn from the case study and are generally applicable to other monthly and daily time step simulation cases:

- Realistic daily flow patterns necessitate the need to consider routing the changes to streamflow. Routing allows past changes to flow to linger in the basin. Streamflow depletions of junior rights from previous time steps can affect the present-day water availability of senior rights. Pure priority order based allocation of available water is therefore complicated by a junior right upstream of a senior right by more than one day of travel time to the stream network outlet. Forecasting can reduce the impacts, but forecasts of future flows are imperfect and must be updated after every time step of the simulation.
- Realistic daily flow patterns can create periods of significant intra-month water availability variability. Monthly water right target demands distributed to daily amounts may not match with day-to-day water availability. High flow pulses may represent a large proportion of the available water in any particular month. Water

rights may experience shortages before and after peak flows when availability returns to low levels.

- Flood control reservoirs have the capacity to store large volumes of water. If the flood control reservoir resides above a conservation storage pool, the water stored by flood control operations can refill conservation storage. Water held in flood control can also offset demands placed on the conservation storage for days or weeks after a flood event while the flood control pool slowly empties. Likewise, flood control releases can augment downstream water availability for days or weeks after a flood event.
- Flood control operations have the capability to substantially alter high flow peak events at and downstream of the dams. Environmental flow modeling that seeks to analyze high flow event magnitude should also consider the effects of flood control in the simulation.
- Monthly aggregated flow erases the temporal separation of intra-month peaks and troughs in the hydrograph. High flow events may last for only a few days but may contain a majority of the flow for the month. Aggregating flows for a monthly time step is equivalent to smoothing the daily water availability for an entire month. Smoothing can mismatch the physical and temporal availability of streamflow with the ability of water rights to capture the streamflow in meeting a monthly target demand.
- Monthly aggregated flows also eliminate the need to consider streamflow routing. Streamflow events and streamflow depletions can be assumed to propagate out of the stream network within the course

of a single monthly time step. Without the effects of routing, priority order is strictly enforced.

- Monthly time step simulations are, therefore, equivalent to daily simulations with perfect streamflow forecasting and with perfect intra-month match between water right demands and water availability. Perfect forecasting means that water availability for junior rights is not unnecessarily constrained and that senior rights do not experience any impacts of past junior right actions.

The results of this research can be applied to the development of additional daily time step WAM datasets or monthly-to-daily conversion of other existing WRAP datasets. Alternatively, new datasets can be developed specifically for daily time step simulation. Increasing pressure on surface water resources to meet a growing population as well as increasing emphasis on maintaining healthy river systems may require consideration of daily time step models for the ability to represent realistic sub-monthly streamflow variability. Future research into daily time step modeling with a priority order based system could extend the research presented here with respect to new methods of forecasting or target setting, or additional methods of disaggregating monthly naturalized flow.

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